NATURAL PHILOSOPHY

FOR

THE USE OF SCHOOLS.

VOL. I.

MECHANICS—HYDROSTATICS—PNEUMATICS—

OPTICS.

MECHANICS,

HYDROSTATICS, PNEUMATICS,

OPTICS,

WITH 238 WOODCUT ILLUSTRATIONS.

FORMING THE FIRST VOLUME OF NATURAL PHILOSOPHY FOR THE USE OF SCHOOLS.

PRINTED AND PUBLISHED BY DIRECTION OF THE

COMMISSIONERS OF NATIONAL EDUCATION IRELAND.

DIEU ET MON DROIT

DUBLIN:

ALEX. THOM & SONS, PRINTERS AND PUBLISHERS,

87 & 88, ABBEY-STREET.

LONGMAN, GREEN, & CO., AND GROOMBRIDGE & SONS, LONDON.

FRASER & CO. EDINBURGH.

MDCCCLXI.

CONTENTS.

SYNOPSIS OF CHAPTERS.

MECHANICS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

HYDROSTATICS.

CHAPTER V.

PNEUMATICS.

CHAPTER VI.

OPTICS.

NATURAL PHILOSOPHY.

MECHANICS.

CHAPTER I.

1. DIVISION OF THE SUBJECT.—The sciences, which, collectively, constitute what is called "Natural Philosophy" are most intimately connected; and the laws of one are, not unfrequently, to a certain extent identical with those of another.

2. *Matter* is that by means of which physical bodies, or those belonging to the external world, act on our senses. It is either solid, fluid, gaseous, or—perhaps we may add—ethereal. The laws which govern solid matter constitute *mechanics.** The latter is divided into *statics*,† which relates to matter at rest; and *dynamics*,‡ which relates to matter in motion. The laws which belong to matter in a fluid state constitute what ought, from analogy, to be called, *hydro-mechanics*, but are comprehended under the terms

* *Mēchanē*, a machine. *Greek.*
† *Statos*, standing. *Gr.*
‡ *Dunamis*, power, *Gr.*:—because matter can produce no mechanical effect, unless it is in motion.

hydrostatics, *hydrodynamics*, and *hydraulics;* those which belong to matter in a gaseous state constitute *pneumatics;* and those which belong to matter in an ethereal state constitute *optics*, *electricity*, &c. All these shall be examined, at the proper time.

3. PROPERTIES OF MATTER.—At the commencement of mechanics it is usual to examine the most remarkable properties of matter. These are impenetrability, extension, inertia, attraction, and—its opposite—repulsion.

Impenetrability is that property which prevents two bodies from occupying the same place. We may compress them into the space previously occupied by one; but, after compression, each occupies as perfectly distinct a space as before. Matter never fills the entire space which it seems to occupy; for all substances are more or less porous. Indeed, Sir I. Newton believed that, if the earth were compressed, so that its particles would be in contact, it would occupy no more than the space of one "cubic inch."

4. *Extension* is that property by which matter occupies some portion of universal space; and *figure* is the boundary of extension. Many bodies have a tendency to assume a definite shape.—Crystalline substances are a striking example of this.

5. *Inertia* is the incapability inherent in matter, either of moving itself when at rest, or stopping itself when in motion. The latter is somewhat difficult to be conceived—since matter in motion is always found gradually to stop of itself; we are, however, to remember that this is due to the external causes which act upon it:—such are friction, the resistance of the air, &c. But for these, matter once put in motion, would continue to move; as actually occurs with the planets—which revolve at this very moment by virtue of the impulse they originally received. Motion, once produced, may be lost by communication to other substances, but it never can be destroyed, except "by an equal, and opposite."

6. Our knowledge of inertia renders many things easy of explanation, which otherwise would be inexplicable.—A bullet thrown out of the hand against a pane of glass will break it to pieces; but fired from a rifle, it will make only *a small hole.* "*Inertia*" has, in the latter case, rendered

it impossible for the *entire* pane to acquire, with sufficient rapidity, the motion necessary for overcoming the cohesion of its particles, and making it fly in pieces. A spent ball, or one fired with a small quantity of powder, will do more damage to the ship it strikes, and kill more men by the splinters, than one which passes through the side with great velocity. It will also make an aperture which can be less easily plugged. If the muzzle of a gun is stopped with snow, clay, &c., or is immersed in water, or if the charge is not rammed home, it will most probably burst on being fired:—the gunpowder being all exploded before its effect reaches the ball, &c., it does not act upon it sufficiently long to put it in motion, and the barrel itself gives way. The same thing would occur in all cases, if a highly explosive compound were used instead of ordinary gunpowder.

7. Rope-dancers avail themselves of the inertia of a long pole, &c., to prevent themselves from falling down.—The inertia of the pole enables them, to a certain extent, to lean against it, in order to gain an equilibrium: and before it has had time to move away, their balance is adjusted. They bring it back gradually to its former horizontal position.

8. Persons are sometimes astonished at seeing an anvil placed on a man's breast and struck with a heavy hammer; but the inertia of the large mass in the anvil prevents the *rapid* [6] blow from being communicated to the person beneath.

9. If we attempt to clinch a nail which has been driven into a board, by merely striking its point, it will be forced out of the wood; but if a large hammer, &c. is laid against its head, it may be clinched with ease. The inertia of the hammer, by preventing it from moving away with sufficient rapidity, causes it to act as if it were a fixed object placed before the nail.

10. When we desire to drive the blade of a chisel, &c., into its handle, we do not strike the blade, for this would injure it; but we strike the handle, which then moves up on the blade—the latter from its inertia, acting, in some measure, as if it were immovable.

11. *Attraction* is that property which enables one body to draw another towards it—there being, as far as our senses enable us to judge, no bond of connexion between them.

Repulsion—precisely the opposite—is that property by which one body forces another to move away from it. When a body attracts or repels another, it "acts mechanically where it is not;" and thus possesses a power which is extremely curious; and which we are quite unable to explain.

12. There are various kinds of attraction.—For instance, that of *gravitation*, which is inherent in all matter: by means of it, every particle attracts every other particle; and, as far as we can know, it acts at all distances. That of *cohesion*, which prevents bodies from falling in pieces; and which, according to its amount, and the extent to which it is counteracted by the opposite property repulsion—supposed to be due to heat, but certainly increased by it—causes them to be soft or hard solids, fluids, &c. This kind of attraction is exerted through very small distances. That of *chemical attraction*, which, as we shall see, changes the nature of the bodies on which it acts; and is exerted, also, only at minute distances. There are, besides these, *electrical* attraction, &c.

13. The permanence of the planets of our system in their orbits, is due to the attraction of gravitation*—so called because it is that property which gives rise to what is called "weight":—they are prevented by the mutual attraction, which exists between them and the sun, from flying off into infinite space. Attraction of gravitation causes a plummet, suspended near a mountain, sensibly to deviate from the perpendicular. This was proved, by the zenith sector giving different meridian zenith distances for the same fixed stars, according as the observer was at the north or at the south side of Schehallion, a mountain in Scotland—on account of the plumb-line being, during the experiments, drawn out of the perpendicular, in opposite directions, by the attraction of the mountain.

14. Since the attraction existing between every two particles of matter is mutual, the sum of the attractions of two bodies is proportional to the mass of each, when the other is constant; and to their product, when both are variable.

15. The force with which two bodies attract each other depends upon the distance between them; and "varies in-

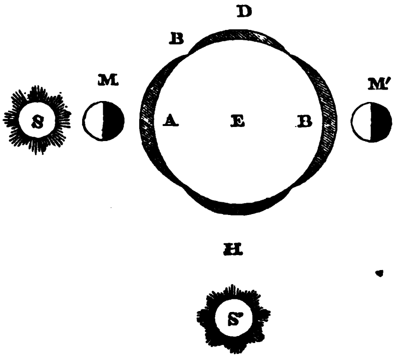
* *Gravitas*, weight. *Latin.*

versely as the square of that distance." Hence, when the space between two bodies is doubled, tripled, &c., their mutual attraction is four times less, nine times less, &c. On the other hand, if they are brought twice as near, three times as near, &c., their attraction is rendered four times as great, nine times as great, &c.

16. The attraction of two bodies being mutual, if nothing prevents them, they will both move with the same force; but not, if they are of different sizes, with the same velocity:—for as the same amount of motion will be distributed among a greater number of particles in the one that is larger; each particle of it will have a proportionably smaller quantity. From this principle it follows, that when a stone falls to the earth, the earth moves towards it; but that the distance through which the earth moves is as many times smaller than the distance through which the stone moves, as the number of particles in the former exceeds the number in the latter. This number is—supposing them homogeneous, and of the same shape—as the cubes of their homologous dimensions. The diameter of the earth is about 8,000 miles; let the diameter of a given sphere of similar materials, falling towards it, be three feet:—the motion of the sphere, falling towards the earth, will then be to the motion of the earth, moving towards it, as the cube of 8,000 miles is to the cube of three feet. The earth will really move; but through a space inconceivably small. Archimedes affirmed that, if another place were given him to fix a machine, he would move the earth:—but he little thought that, while he spoke or wrote this, the alteration in position, however trifling, of the matter of his muscles, &c., caused not only the earth, but the entire solar system, and perhaps other and still more stupendous systems, to be moved to an infinitely minute it is true, but to a real amount. If only one of the mutually attracting bodies is movable, it will traverse the whole distance between it and the other body.

17. THE TIDES are a consequence of the attraction of gravitation. The earth revolves on its axis once each day: and the moon is retained in its orbit by the mutual attraction which exists between it and the earth. The knowledge of these two facts enable us easily to explain the tides.

FIG. 1.



Let M, fig. 1, and M' represent different positions of the moon, with respect to E, the earth; let S and S' represent different positions of the sun. A and B quantities of water at different sides of the earth, are attracted by the moon M, with very different force, because of their different distances from that planet. Hence A will move much more towards M than either the mass of the earth E, or the water B. In other words, the water A will fall sensibly towards the moon—which of course also falls towards it:—there will, therefore, be a mass of water under M at A; and this mass will be always found under M, although the part of the earth beneath it continually changes, on account of the earth's revolution upon its axis. This mass of water constitutes the *tide* at that side of the earth where it is found. But there must necessarily be a tide, at the same time, on the opposite side of the earth also:—for E and A fall more rapidly towards M, than B, because nearer to M: B therefore is left behind. Hence the waters accumulate, also, at the point farthest from the moon; this accumulation will always be found there, for the reason already given, although the part of the earth beneath continually moves away; and thus a tide is produced at the part of the earth most remote from the moon. The two masses of water are equal; for that which is at B falls as much less rapidly towards the moon than E, as E moves less rapidly towards the moon than A. The water flows in from all directions to form these masses; and, at each side, in the spaces between them, there is the least water:—that is, in these intermediate places, the tide is *out*.

18. While the water is flowing towards the parts which

are under the moon, currents are produced which are affected by the interruptions they meet with from islands, promontories, &c. They are modified, also, by the motion which they receive being compounded of two motions—and being therefore, for reasons we shall explain presently, in the direction of neither of them. One of these motions tends to bring the water towards the equator, to supply the place of that which is drawn away by the moon; the other is opposite to the direction of the earth's rotation on its axis, and is due to the water coming from the poles, not having so great a velocity as the parts of the earth towards which it flows, and being therefore left behind.

19. The inertia of the water which [6] makes it impossible for motion to be communicated to it instantaneously, causes the highest portion of the tidal wave to be at some distance from that point which is immediately under the moon; and where, without sufficient reflection, we might expect it to be. The waters cannot *suddenly* obey the force of the moon's attraction; and, in the mean time, the earth revolves a little on its axis, so as to bring a new point under the moon. Hence it is high water on a meridian about 30° eastward of the moon.

20. These facts enable us to understand why there should be two tides in about twenty-four hours. There is a tide on a given side of the earth, because it is *next* the moon, and another on the same side in about twelve hours after, because it has become the part *farthest* from the moon.

21. The tide is later in any place on each succeeding day:—because that place will not return to its former position in less than a day: and it has, besides, to follow the moon, which in the mean time, has moved on in its orbit.

22. The sun also causes tides; but, although it is much larger than the moon, its effect on the water is much less, on account of its greater distance. Sir I. Newton has shown that the action of the moon is three times as great as that of the sun. When the sun and moon are in conjunction, that is, at the *same* side of the earth, for instance at S and M, or in opposition, that is, at *different* sides, as at S and M′—or in other words, at new and full moon, there are *spring* tides, because the effects of the sun and moon are then united. The spring tides are not highest,

however, exactly at new or full moon, but a little after. When the effects of the sun and moon are opposed, as at S′ or M or M′—the moon being in quadrature, there are *neap* tides.

23. The tides are variously affected by the sun—which brings them on sooner, when the moon is in her first and third quarters; but keeps them back when she is in her second and fourth.

24. When the sun or moon, or both, are nearest to the earth, the tides produced by them are highest. Hence the tides are greatest after the autumnal, and before the vernal equinox; because the sun is nearer to the earth in winter than in summer.

25. If the sun or moon were actually at the pole, the water would not be raised unequally at different parts of the equator, or any parallel of latitude. Hence the nearer the sun or moon to the pole the less the inequality in the height of the water, and the nearer to the equator the greater. Spring tides, therefore, are highest, and neap tides lowest, about the time of the equinoxes; but on the contrary, spring tides are lowest, and neap tides highest, at the solstices. When the moon is in the equator, both the tides of the lunar day—the time which the moon takes to return again to the same meridian—are equal, at places having a northern or southern latitude. But as she declines to either pole, the two tides which occur at the same time are not in the same parallel, but in different ones: and hence the highest point of one of the tides—that at which the moon is nearest to the zenith—will be nearer to the given place than the highest point of the other, since one of the parallels will be nearer to it than the other.

26. There is no doubt that the action of the sun and moon produces tides in the atmosphere.

27. *The attraction of cohesion*, or "molecular attraction," is that which keeps the particles of the same mass of matter together. It may be exemplified by rubbing strongly against each other the flat sides of two hemispheres of lead: they will adhere, and with considerable force. This adhesion is not to be attributed to the pressure of the atmosphere on their convex surfaces, on account *of no air being between* them:—for the effect is the same

when they are placed under the exhausted receiver of an air-pump.

28. The cohesion existing between the particles of fluids may also be easily illustrated. If a thin plate of any substance, not repelled by water, is wetted with it, then suspended horizontally from the beam of a balance, and nicely counterpoised, very little additional weight will cause it to ascend; but if it is made to lie on the surface of water, it will require a comparatively large weight to raise it. The additional weight is rendered necessary by the force which must be expended in separating, from the general mass of fluid in the vessel, the particles of water adhering to the plate.

29. In many instances, all that is required to make bodies cohere, is to bring them sufficiently near each other. In plate glass manufactories, after the sheets intended for mirrors have been finished and laid together, it has been sometimes found impossible to separate without breaking them; and the aggregated masses have even been cut, and have had their edges polished, as if they formed but one piece.

30. It is probable that the attraction of cohesion may cause rubbing surfaces to wear more rapidly, by bringing them more closely together: and the friction, from this cause, must naturally be greater when the rubbing surfaces are of the same material. Hence, one reason why metals of the same kind do not work well together.

31. The cohesion of the particles of different bodies varies greatly. The following table shows the weight required to tear asunder a prism of the following substances, having a section equal to one square inch; and also, what length of each would break by its own weight:—

	Lbs.	Feet.
Memel Fir, ...	9,540	40,500
Sycamore, ...	9,630	35,800
Elm, ...	9,720	39,050
Oak, ...	11,880	32,900
Beech, ...	12,225	38,940
Larch, ...	12,240	42,160
Christiana Deal, . .	12,346	55,500
Teak, ...	12,915	36,049
Ash, ...	14,130	42,080

	Lbs.	Feet.
Cast lead,	1,824	348
Cast tin,	4,736	1,496
Yellow brass,	17,958	5,180
Cast copper,	19,072	5,003
Cast iron,	19,096	6,110
English malleable iron,	55,872	16,938
Swedish ditto,	72,064	19,740
Cast steel,	134,256	39,455

That is, a bar of steel 39,455 feet long, suspended vertically, will break by its own weight.

32. An iron bar, 1,000 inches long, and an inch square, will be lengthened one inch by a weight of 36,000 lbs.

2	inches by	45,000
4	,,	54,000
8	,,	63,000
16	,,	72,000

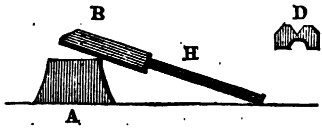
and will then break.

Tenacity is, sometimes, greatly increased by wire-drawing or hammering—copper being nearly doubled, and lead more than quadrupled in strength by these processes. But the consolidation is produced chiefly at the surface; hence a slight notch with a file will often seriously diminish the strength of a metallic rod. Metals are deprived of the brittleness they have acquired during the process of hammering, by being annealed—that is, exposed to a red heat.

33. Besides attraction, the antagonist force, called "repulsion," is found to exist between the particles of all bodies; and prevents their being brought nearer than within a certain distance of each other. It is perhaps due to heat, and certainly is always modified by an increase or diminution of it.

The repulsion arising from heat may be curiously exemplified by placing a ground bar of copper, B, fig. 2, about five inches long and half an inch thick, and attached to about eight inches of thick iron wire H, on a cold flat block of lead A. When the lead becomes *heated, it raises up* the brass by its repulsive power, and

FIG. 2.



when it cools, the brass falls. The repetition of this gives rise to a kind of musical sound, which will continue until the temperature of the metals becomes uniform. The shrillness of the sound is greatly increased by a channel cut in A or in B:—a section of the latter is seen at D. Brass and lead answer best for this experiment, on account of the great difference between their conducting powers.

34. When bodies are affected by repulsion, the result may be anticipated, from what has been said regarding attraction [14, &c.] Thus, when a gun is discharged, the ball and the closed end of the gun are separated by the mutually repulsive actions of the particles of gas generated: and the effect continues until the ball passes into the external atmosphere. The amount of motion, therefore, in the gun and its carriage, will be nearly equal to that of the ball and half the weight of the powder moving with the same velocity as that of the ball. Supposing a twenty-four pounder to be 10 feet long, and to weigh 6,400 lbs., and the charge of powder to be 8 lbs., the motion of the ball and half the powder, while *they* are in the gun, may be represented by $(24+4)\times 10=280$. But, as the cannon weighs 6,400 lbs., its motion will be $\frac{280}{6400}=\frac{7}{160}$ of a foot, or half an inch nearly. Such, therefore, would be the recoil of the gun, if it were free to move:—and its velocity would be as much less than that of the ball, &c., as it would exceed them in weight. It is scarcely necessary to remark that this would be its motion during the passage of the ball through it; and it would continue to move for some time afterwards.

35. Glass lenses are used in optics for the production of coloured rings—for which purpose they are merely, as we shall see, pressed together; if they are heated, the rings will close in, which shows that the repulsion caused by the heat, has separated the pieces of glass to a greater distance than before.

36. The repulsion produced in this way may be exemplified, also, by pouring a drop of water into a platinum crucible, raised to a red heat. The water will not come into contact, in such circumstances, with the metal, and *it is possible to* render the space between them distinctly

visible; which causes the evaporation, even of a highly volatile liquid, to be exceedingly slow. Fluids in this state have an ellipsoidal or, when in small quantity, a spheroidal form: and revolve with great rapidity, on a changeable axis. And under these circumstances their very properties are altered:—a surface of copper or of silver is not acted upon by a spheroid of nitric acid; nor a surface of zinc or iron by a spheroid of dilute sulphuric acid. This arises from want of contact, and not from want of energy in the fluid; since cold silver plunged into the spheroid of nitric acid is rapidly dissolved. Anhydrous sulphurous acid boils, in ordinary circumstances, at 14°; but, in the spheroidal form, its evaporation is scarcely perceptible. A quantity of water, however, projected upon it will be frozen; so that ice may be produced in a vessel intensely hot. This is due to the rapid evaporation of the acid, which then takes place.—Like other liquids, when boiling, its temperature cannot be higher than its boiling point; for any excess of caloric is carried off by the vapour. But its boiling point is considerably under the freezing point of water. And the power which the human hand is known to possess of being plunged deliberately and with impunity into melted copper, &c., is attributed to the fluids which it contains assuming the spheroidal form, and thus becoming incapable of receiving heat with the usual facility.

37. If a steam boiler becomes red hot, from neglect in pumping, the water afterwards thrown upon it may assume the spheroidal state, and then flashing into steam of enormous pressure, may burst the boiler. This is rendered highly probable, by experiments made on the subject. Also, when the scale on the interior of a boiler cracks, the water gets into contact with highly heated metal, and in many cases becomes spheroidal. These facts account for the diminished supply of steam, often perceived before boilers burst. It is proper to remark that water begins to be spheroidal, and to lose its power of evaporating, at something less than 500° Fahr. Mercury has been frozen by plunging it into a spheroid of ether and solid carbonic acid.

38. We may exemplify the repulsion of one body for *another, at ordinary* temperatures, by carefully placing a

small needle on the surface of water:—it will repel the latter, to such an extent, that so large a hollow will be formed as will cause the water displaced to be heavier than the needle; which, therefore, will float.

39. LITHOGRAPHIC PRINTING.—The attraction and repulsion exhibited by different substances towards each other, are beautifully applied to practical purposes, in the process of *lithography.** The drawing, &c., to be lithographed, is written with a peculiar kind of ink—between which and water there is a strong repulsive action—and is transferred by pressure to a fine grained and very porous stone; or a reverse drawing is made at once on the stone When an impression is to be taken, the stone is wetted, and freely absorbs the moisture, except in those places that have been inked, which, therefore, will repel the water and remain quite dry. A roller, containing the same kind of ink, is next passed over the stone, and the ink adheres only to those places which have repelled the water, the other parts remaining perfectly clean. So delicate is the manipulation required in this process, that touching the stone with the finger will leave an unctuous mark to which the ink would adhere, and which, therefore, would be accurately, though unintentionally, transferred to the paper in printing. When the stone is inked the paper is placed upon it, and pressure is applied.

Another kind of attraction is called "capillary." It is, however, as we shall show when we treat of hydrostatics, only a modification of molecular attraction.

40. MOTION is simply "change of place;" and it is greater or less, according as that change is greater or less—no regard whatever being had to the time in which the change is effected. Thus, if one body moves five inches in a second, and another five inches in 5,000 years, the motion of both is the same. But if one body moves fifty feet in one minute, and then stops, and another moves forty-nine feet per second, for two seconds, and then stops, the motion of the former will be *less* than that of the latter. Motion is "proportioned to the space over which the body, which has it, would travel."

Any thing that produces motion is called a force.

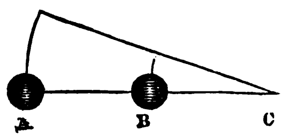
* *Lithos,* a stone; and Grapho, I write. Greek.

41. Motion is said to be either "absolute" or "relative." Absolute motion is actual change of place.—Thus, when a horse gallops, his motion is absolute. Relative motion is change of distance from another object.—Thus, if two horses gallop with equal rapidity in the same direction, they will have no relative motion; but if they move with different rapidities in the same direction, their relative motion will be the difference between their absolute motions. If they move in opposite directions, their relative motion will be the sum of their absolute motions. A body may be absolutely at rest, though relatively in motion: thus, the shore is in motion, with reference to a ship putting out to sea.

42. VELOCITY is quantity of motion with regard to a given time—no attention being paid to the entire space traversed. Hence one body may move with a greater velocity than another; though on the whole, it changes its place to a less extent.

43. The farther a body is from the centre of motion, the greater its velocity.—For, if two bodies, A and B, fig. 3, are immovably connected by an inflexible rod, each will describe round C, the centre of motion, an arc which will measure the same angle;—that is, the "angular velocity" of both will be the same. But arcs, having the same number of degrees, are as the radii which describe them. And the given arcs are the spaces described, respectively, by the bodies A and B; their radii being the distances of A and B from C, the centre of motion. Therefore, since these spaces, or arcs, are proportional to the velocities of A and B—because described in equal times—the velocities of A and B are proportional to their distances from C.

FIG. 3.



44. Hence the velocity of a body at or near the equator, is greater than that of one which is at, or near the poles.—The water, therefore, as it flows from the poles towards the equator [18], not having the velocity of the earth at those points over which it passes, is left behind in the *diurnal revolution.*

45. Velocity is either *uniform* or *accelerated;* and, if the latter, it is either *uniformly*, or *variably* accelerated. When the velocity is uniform, it is the same at every period during the time of motion; and "the spaces described, under its influence, in equal times will be equal." Hence, when the velocity is uniform, "the whole space described is equal to the velocity—or space described during a unit of the time—multiplied by the time." That is, calling the space S, the velocity V, and the time T, $S = TV$. For if a body travels during $10''$ with a velocity of 40 feet per second, it will have travelled 10×40ft.$=400$ft.

46. And the greater or less the time, the greater or less the space; that is, "the space is proportional to the time," or $S \propto T$.

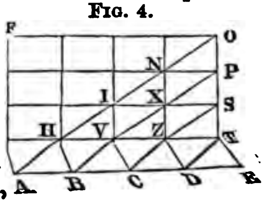
47. "The velocity is equal to the space divided by the time," or $V = \frac{S}{T.}$ For, if a body travels 400ft. in $10''$, it travels, $\frac{400}{10}$ft., or 40ft. in $\frac{10''}{10}$, or $1''$.

48. "The time is equal to the space divided by the velocity," or $T = \frac{S}{V.}$ For, if a body travels 400 feet with a velocity of 40 feet per second, the time required is $\frac{400''}{40} = 10''$.

49. When the velocity is *accelerated*, it is greater at successive periods; and if it is *uniformly* accelerated, the "increments of velocity will be equal in equal times." Uniformly accelerated velocity is produced by a uniform force *continuing* to act.

50. With a uniformly accelerated velocity "the space varies as the square of the time, or of the last acquired velocity."—For, indicating the times and spaces traversed, by lines proportional to them; and considering the velocity as uniform during each indefinitely short period of time: let A E, fig. 4, representing the entire time, be divided into equal *portions by B, C,* and D. At A,

Fig. 4.



the velocity with which motion commences is nothing; and the space traversed by means of it may be represented by a point. At B it has increased so that the space, corresponding to that instant of time, will be represented by BH. At C it will be represented by CV+VI=2BH:—for BH must be the increment in each successive equal period. In the same way, at D, the space is equal to DN; and at P, to EO. At all the points between A and E the spaces would be represented by uniformly increasing lines which, together, would form the triangular surface AOE:—therefore the surface AOE will represent the space traversed in the whole time AE. Hence the space traversed in the times AB, AC, &c., is to the space traversed in the time AE, as the triangles having these lines for their bases:—or, since these triangles are similar surfaces, as the squares of their homologous dimensions. But the lines AB, AC, &c., are their homologous dimensions—and also represent the times; therefore the spaces are as the squares of the times. BH, CI, &c., likewise are homologous dimensions—and represent the last acquired velocities: hence the spaces are as the squares of last acquired velocities. It follows that, when the velocity is uniformly accelerated, the whole space described is equal to the space described during the first unit of time, multiplied by the square of the time. Also,

51. The spaces described in successive portions of time, AB, BC, CD, &c., are as the odd numbers 1, 3, 5, &c.; this will be evident on inspecting the surfaces representing the spaces:—for BHIC=3AHB; CIND=5AHB, &c.

52. The space traversed under the influence of a uniformly accelerating force is only one half of what it would have been, had the last acquired velocity been the velocity at every instant. For, let EO, fig. 4, the last acquired velocity, be the velocity at every instant of the time represented by AE: then the space described at each instant—corresponding to each point of AE—would be represented by a line=EO: but a series of such lines would form the rectangle AFOE=2AOE— that is, twice the space described when the velocity is uniformly accelerated.

53. The laws which relate to a uniformly accelerating force are applicable also to a uniformly retarding one; which may be considered as a uniformly accelerating one,

in an opposite direction; and which, therefore, destroys as much velocity as it would have generated in the same time, had it been an accelerating force.

54. ATTRACTION OF GRAVITATION.—A body is found to fall, under the influence of gravity, about $16\frac{1}{12}$ feet per second.* In estimating the effect of gravity, considered as a uniformly accelerating or retarding force, the resistance of the air is not taken into account; nor the difference of the force of gravity, at different distances from the earth's surface. The latter, however, must be small; for the action of gravity at the surface of the earth is to its action at any distance from it, as the square of the earth's radius plus the distance, is to the square of the earth's radius:—that is, x being the distance, as $(4{,}000+x)^2$ is to $(4{,}000)^2$. But, since x must always be inconsiderable, it may be neglected; and the ratio may be looked upon as one of equality.

55. To find the space traversed under the influence of gravity, when the time is given. "Multiply $16\frac{1}{12}$ feet by the square of the time."†

EXAMPLE.—A stone takes 3″ to reach the bottom of a precipice; what is the depth of the latter? $16\frac{1}{12}\times 3^2 = 16\frac{1}{12}\times 9 = 144\frac{3}{4}$, the depth of the precipice.

56. To find the space, when the last acquired velocity is given. "Divide the square of the last acquired velocity by $64\frac{1}{3}$."‡

EXAMPLE.—How far must a body fall, to acquire a velocity of 1,500 feet per second? $(1{,}500)^2 \div 64\frac{1}{3} = 34974{\cdot}0933$ feet.

57. To find the last acquired velocity, when the time is given. "Multiply the time by $32\frac{1}{6}$."§

* In the latitude of London it falls 16·095 feet.

† Let S be the space through which the body falls; let g be the force of gravity at the end of the first second, which is equal to [52] $32\frac{1}{6}$ feet. Then [50] $S=\frac{gt^2}{2}$:—that is, the space described in one second, multiplied by the square of the number of seconds.

‡ For, v being the last acquired velocity at the end of any period of time, $v=gt$, or the velocity at the end of the first second multiplied by the number of seconds, [50]; $v=g^2t^2$; and $\frac{v}{2g}=\frac{g^2t^2}{2g}$. But [55] $S=\frac{gt}{2}=\frac{g^2t^2}{2g}$; Therefore $S=\frac{v^2}{2g}$.

§ *Since [50] $v=g\,t$.*

EXAMPLE.—If a body continues falling for 9·5″, what will be its last acquired velocity? $9{\cdot}5 \times 32\frac{1}{6} = 305$ feet 7 inches.

58. To find the last acquired velocity, when the space is given. "Multiply twice the space by $32\frac{1}{6}$, and take the square root of the product."*

EXAMPLE.—What will be the last acquired velocity of a body that has fallen 1,000 feet? $\sqrt{(2 \times 1{,}000 \times 32\frac{1}{6})} = 253{\cdot}64$ feet.

59. To find the time, when the last acquired velocity is given. "Divide the given velocity by $32\frac{1}{6}$."†

EXAMPLE.—For how many seconds must a body fall to acquire a velocity of 1,600 feet per second? $1{,}600 \div 32\frac{1}{6} = 50''$ nearly.

60. To find the time, when the space is given. "Divide the space by $16\frac{1}{12}$: and take the square root of the quotient."‡

EXAMPLE.—How long will a body take to fall 1,189 feet? $\sqrt{(1189 \div 16\frac{1}{12})} = 8{\cdot}6''$.

61. A uniformly retarding follows the same laws as a uniformly accelerating force; except that instead of generating, it destroys velocity [53].

EXAMPLE.—If a body is projected upwards with a velocity of 1,690 feet per second, how far will it ascend before it stops; and how long will it take to return to the earth? —Gravity [56] will generate a velocity of 1,690 feet per second by falling 44,395 feet nearly; and that space [60] would be traversed in 52·54″ nearly. It will therefore travel 44,395 feet and then stop; but it will return to the earth in the time it took to ascend. Hence it will reach the earth in $2 \times 52{\cdot}54'' = 105{\cdot}08''$: and will have travelled 88,790 feet nearly.

62. When a body is projected upwards, its velocity at every point of its ascent is as the square root of the space it has still to describe.§ And, at every point during

* For since [56] $S = \frac{v^2}{2g}$; $v^2 = 2gS$; and $v = \sqrt{2gS}$.

† For since [50] $v = gt$; $t = \frac{v}{g}$.

‡ Since [55] $S = \frac{gt^2}{2}$: $t^2 = \frac{2S}{g}$: and $t = \sqrt{\frac{2S}{g}} = \sqrt{S \div \frac{g}{2}}$.

§ $S \propto v^2$ [50].—Therefore $v \propto \sqrt{S}$.

descent, it will have the same velocity as it had at that point during ascent.

63. If a body have an initial velocity—that is, if when gravity begins to act, it is already in motion, through the influence of some other force—"we must *add* the space that would be traversed under the influence of the force producing that velocity, to the space through which gravity would cause the body to pass in the same time."

EXAMPLE.—A body is projected downwards with a velocity of 100 feet per second: how far will it have descended in 5″?

Under the influence of its initial velocity it would in 5″ travel 500 feet [45]. Under the influence of gravity, it would travel, in the same time, $25 \times 16\frac{1}{12}$ [55]$=402\frac{1}{12}$ feet. Therefore, under the influence of both, it will travel $500+402\frac{1}{12}=902\frac{1}{12}$ feet.

64. If a body is projected upwards, the space it would have travelled in the given time, under the influence of gravity, must be *subtracted* from the space it would have traversed, under the influence of its initial velocity.

65. We may find the space described by a body under the influence of gravity, during any particular second, "by adding $16\frac{1}{12}$ feet to the last acquired velocity of the preceding second;" since this is the increment during each second.

EXAMPLE.—If a body continues falling for 6″, how long will it have travelled in the sixth second?—Its last acquired velocity at the end of the fifth second will be $5 \times 32\frac{1}{6}$, [57]; hence it will have fallen in the sixth second, $35 \times 2\frac{1}{6}+16\frac{1}{12}$. $=176\frac{11}{12}$ feet.

66. Knowing the space travelled over in the last second, we can ascertain how long a body has been falling, and how far it has fallen.

EXAMPLE.—A body falls through half its descent, in the last second; how long was it falling, and how far did it fall? Let t represent one less than the number of seconds. In t'' it fell $\frac{S}{2}$ or half the space; it also fell [55] $t^2 \times 16\frac{1}{12}$ feet:—therefore $\frac{S}{2}= t^2 \times 16\frac{1}{12}$. It fell in

the last second $\frac{S}{2}$ or half the space; and also [65] $t \times 32\frac{1}{6} + 16\frac{1}{12}$, therefore $\frac{S}{2} = t \times 32\frac{1}{6} + 16\frac{1}{12}$. Putting both the values of $\frac{S}{2}$ equal, we have $t^2 \times 16\frac{1}{12} = t \times 32\frac{1}{6} + 16\frac{1}{12}$: and from this equation we find $t = 2{\cdot}4142''$. Hence $t+1 = 3{\cdot}4142''$, the whole time of falling.—Consequently [55] the space travelled over during the last second is 93·76 feet; and the whole space through which it falls $= 2 \times 93{\cdot}76 = 187{\cdot}52$ feet.

67. If the entire weight of a falling body is not effective, the space through which it moves in a given number of seconds is equal to "the space through which it would have fallen, multiplied by the quotient obtained by dividing its effective part by the entire mass to be moved."*

EXAMPLE.—Two weights, one 7 lbs. and the other 13 lbs., are suspended over a pulley. How far will the former ascend and the latter descend in 2''? $2^2 \times 16\frac{1}{12}$ [55] $\times \frac{13-7}{13+7} = 19{\cdot}3$ feet.

68. If there were an aperture through the earth from pole to pole; supposing the earth's axis to be 7,900 miles, and that a body were to fall along it; the velocity of that body, at the centre of the earth, would be 25,834 feet per second; and its passage to the opposite pole would be made in 42′ 16¼″.

69. WEIGHT.—The attraction of the earth for bodies on its surface gives rise to what is called "weight." As each particle of a body is individually attracted, the sum of the attractions—or the weight, will be proportional to the number of particles, no reference being had to size.

* The space traversed by the mass will be as much less than what would have been traversed by the effective part, if it acted alone, as the mass is greater than the effective part. For the quantity of motion being the same in both cases, the larger the mass the smaller the space it will traverse. That is, calling the effective part $W-W'$, the number of seconds t, and the space traversed by the whole mass S, we shall have $W+W' : W-W' :: t^2 \times 16\frac{1}{12} : S$. Therefore $S = t^2 \times 16\frac{1}{12} \times \frac{W-W'}{W+W'}$.

Weight, therefore, is used as a means of ascertaining the quantity of matter contained in a body.

70. The nearer a body is to the earth, the more it will weigh. Ordinary changes of distance, however, do not produce a sensible effect: and a difference becomes perceptible only when the change of distance is considerable. 1,000 lbs., on the surface of the earth would, if carried to the top of a mountain four miles high, show, by means of a spring balance, a loss of weight equal to 2 lbs. But, if carried four miles into the earth, it would show a loss of 1 lb., its greater proximity to the centre of gravity of the earth being more than counterbalanced by the action of the mass above it.

The force of gravity decreases from the poles to the equator. 1,000 lbs., carried from this to the pole, would gain 3 lbs.; but carried from this to the equator it would lose $4\frac{1}{4}$ lbs.

71. The same body would have a different weight in different planets. A cubic inch of lead weighs, on the surface of the earth, $6\frac{1}{2}$ oz.; in the sun it would weigh $11\frac{2}{5}$ lbs.

72. The earth is nearly four times as dense as the sun; but the latter is so much larger than the former, that a man of moderate size would weigh two tons on its surface; and, with his present muscular strength, he would be unable even to move. In any of the newly-discovered planets he would weigh but a few pounds.

73. *Meteoric Stones* are thought, by some, to be bodies projected from volcanoes in the moon, with such a velocity as to carry them out of the sphere of the moon's, and within the sphere of the earth's attraction. It is calculated that, if one of them were projected with the initial velocity of 10,992 feet per second—or with more than four times the velocity of a ball, just discharged from a cannon, it would come within the sphere of the earth's attraction, and revolve round it like a satellite; and the primitive impulse, if sufficiently great, might at once, or the disturbing influence of the sun might, after a time, precipitate it to the earth.—Its velocity in passing through the air would, it is supposed, cause ignition. Meteoric bodies of great magnitude, occasionally approach very near the earth. One of them, estimated to be 600,000 tons in weight, and moving with a velocity of 20 miles per second, passed within 25 miles of it. Only a small fragment, however, reached the earth.

All meteoric stones are found to be almost identical in composition.

74. MOMENTUM may be defined "the effect producible by a given quantity of matter, possessing a given amount of motion;" or, "the quantity of motion which may be imparted by one body to another."—For, the entire effect which one body is capable of producing on another is, ultimately, reducible to the quantity of motion it is capable of imparting to the other. In estimating momentum, both the mass and velocity are to be taken into account; for momentum cannot exist without both of them:—if either of them is invariable, momentum is proportional to the other; and if both are variable, it varies as their product. Nothing affects momentum, unless it affects the mass, or the velocity, or both. To increase the momentum we must increase the quantity of communicable motion; and this may be effected either by adding to the body, having the momentum, a number of particles, each possessing the same motion as those to which they are added—which is "to increase the mass," without altering the velocity; or, by adding to the motion of each of the particles, without increasing their number—which is "to increase the velocity," without altering the mass; or, finally, we may increase the quantity of communicable motion, by increasing both the number of particles, and the quantity of motion existing in each. Calling the momentum M, the quantity of matter or number of particles Q, and the velocity V, the changes produced on the momentum by altering the mass, or velocity, or both, are thus briefly expressed:—

$M=QV$.—Therefore, M is directly proportional to Q, when V is constant; but to V, when Q is constant: and, to their product, when both are variable.

Q is inversely proportional to V, and V is inversely proportional to Q, when M is constant.

EXAMPLE 1.—What must be the velocity, to produce, with a mass represented by 27, a momentum represented by 162?

$$M=QV\text{:—that is, } 162=27\times V$$

$$\text{Therefore } V=\frac{162}{27}=6\text{, the required velocity.}$$

EXAMPLE 2.—What must be the mass, to produce, with a velocity represented by 16, a momentum represented by 144?

$$M=QV;\ \text{that is, } 144=Q\times 16$$

$$\text{Therefore } Q=\frac{144}{16}=9;\ \text{the required mass.}$$

EXAMPLE 3.—A certain momentum is produced by a velocity represented by 15, and a mass represented by 100: but it is found inconvenient to use a mass greater than 75. What must the velocity be, to leave the momentum as before?

Q is inversely proportional to V: therefore
100 : 75 :: the required velocity : 15.

$$\text{Hence the required velocity}=\frac{100\times 15}{75}=20.$$

A mass represented by 100 with a velocity expressed by 15, will produce the same momentum as a mass represented by 75 with a velocity expressed by 20. For

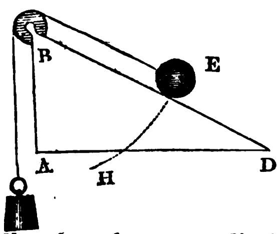
$$100\times 15=75\times 20.$$

75. Although two momenta are equal when the products of the masses and velocities are equal, we are not to suppose that the *relative* amounts of the mass and velocity are of no consequence.—For example, the momenta of a large hammer, with a small velocity, and that of a small hammer, with a large velocity, may be equal; and yet it would be incorrect to conclude, they may be used indiscriminately. The small hammer will drive a nail, without shaking the object into which it is driven, while the large one would overturn, or shatter it:—for the small one moves so fast, that there is not sufficient time [6] to overcome the inertia of the body, into which the nail is driven. On the other hand, it is found most advantageous, in certain processes, to use enormous hammers, moved by steam; although much smaller ones would, the velocity being sufficiently great, produce the same momentum.

76. REACTION is action equal and opposite to a given one. When bodies are at rest, it is opposed to pressure, &c., and prevents the motion which, without it, would occur.—Thus, a body lying on a table, cannot fall to the ground, *from the difficulty* of compressing the particles of the table,

on account of their mutual repulsion. The reaction of a body is always perpendicular to its surface. This is evident, when there is question of a body, kept at rest by reaction only: as, when it is on a perfectly smooth and horizontal plane; but it is equally true when it is kept at rest, by two or more forces. Let E, fig. 5, be a body, retained on the surface B D by a cord. The only motion the cord will allow E to receive from gravity, must be such as would cause it to traverse the curve, indicated by the dotted line E H:—but this curve is perpendicular to B D, at the point of contact. The inclined plane, therefore, prevents motion in a direction perpendicular to its surface—which could be effected only by an equal force, acting in an opposite direction: that is, in a direction, also, perpendicular to B D. Hence the reaction of B D is perpendicular to it.

FIG. 5.



77. COLLISION OF BODIES.—When reaction has reference to one or more bodies actually in motion, or capable of being moved, it is said to arise from *impact*, *percussion*, or *collision*. Percussion differs from pressure, only by requiring a shorter time to produce its effect. Percussion is *direct*, when it is in a line passing through the common centre of gravity of the bodies coming into collision, and is perpendicular to the plane of impact. It is *oblique*, even though it be in a line perpendicular to the plane of impact, if this line does not pass through the common centre of gravity. The laws which govern oblique may be easily discovered, from what we shall say of direct impact, and of the "composition and resolution of forces."

78. When reaction arises from impact, the body which is struck may, or may not be in motion; and neither, or both of the bodies may be perfectly elastic.—A "perfectly elastic body" is one that recovers its shape, with a force equal to that which compressed it. A "perfectly non-elastic body" is one that has no tendency whatever to recover its shape when compressed: or one that is incapable of compression. No substance in nature is either perfectly elastic, or perfectly

non-elastic; though many, without any sensible error, are looked upon as such. We shall confine ourselves to bodies considered as perfectly elastic, or perfectly non-elastic:—if only one body is elastic, or neither is *perfectly* elastic, the effect will be modified, but in a way that can be anticipated from the principles we are about to develop. Reaction, when produced by impact, arises from the repulsion of the particles of the bodies: force is expended in overcoming this repulsion, but when the body is elastic, it is afterwards restored—though changed to an opposite direction—by the elasticity, which the same repulsion has produced.

79. When bodies come into collision, the sum of their momenta, in any direction, is the same after as before their collision:—for nothing can diminish this sum, but a momentum in the opposite direction; and none such is considered to be in action.

80. Since, after collision, the sum of the momenta in any given direction, remains unchanged, the centre of gravity—a point at which these momenta may be supposed to be concentrated—retains its original rest or motion.

81. The preceding principles afford us a means of determining the laws which govern, either non-elastic or elastic bodies. Let there be two non-elastic bodies, A and B; V being the velocity of A before impact, and V′ that of B before impact. As they have no elasticity, there is nothing to separate them, after they come into contact; they will, therefore, move on together with some common velocity:—let this be v. Since the sum of their momenta, in the direction of the motion of A, is the same after as before impact,

$$AV+BV'=(A+B)\,v\text{; and}$$

$$v=\frac{AV+BV'}{A+B}$$

This equation will enable us to find any one of the quantities, which may be unknown.

Example.—A=6, and B=6; V=11, and V′=—11, being in the direction opposite to V.—Then

$$\frac{AV+BV'}{A+B}=\frac{6\times 11-6\times 11}{6+6}=0$$

Consequently, the bodies will, after impact, remain at rest.

82. *The Ballistic Pendulum* is a machine which is used for estimating the velocities of cannon balls; and depends on this equation. It consists of a large block of wood, attached to the end of a strong iron stem, vibrating on a horizontal axis—like the pendulum of a clock. The ballistic pendulum being at rest, the cannon ball is fired into the block; and remaining within it, causes the whole apparatus to vibrate—the arc being greater or less, according to the velocity of the ball. The extent of the vibration is ascertained by means of a graduated arc, placed under the pendulum, and an index attached to the block. The velocity of the pendulum is calculated, from the arc of vibration; and the velocity of the cannon ball, from that of the pendulum.

83. If the bodies are perfectly elastic, let the velocity of A after impact be v, and that of B, v'. As the sums of the momenta before and after impact are equal [79], $AV+BV'=Av+Bv'$. And

$$v=\frac{2BV'+(A-B)V}{A+B}$$

$$v'=\frac{2AV-(A-B)V'}{A+B}*$$

84. We may find, from these equations, the value of any one of the quantities contained in them.

* For, during an indefinitely short space of time, the two bodies will, after collision, have a common velocity; this, as in the case of non-elastic bodies, [81], will be $\frac{AV+BV'}{A+B}$; and the velocity *lost* by A will be the difference between this common velocity and the original velocity of A; that is,

$$v=V-\frac{AV+BV'}{A+B}=\frac{AV+BV-AV=BV'}{A+B}=\frac{BV-BV'}{A+B}=B.\frac{V-V'}{A+B}.$$

The velocity *gained* by B will be the common velocity, minus the original velocity of B; that is,

$$v'=\frac{AV+BV'}{A+B}-V'=\frac{AV+BV'-AV'+BV'}{A+B}=$$

$$\frac{AV-AV'}{A+B}=A.\frac{V-V'}{A+B}.$$

But, as the bodies are perfectly elastic, the effect is twice as great as if they were non-elastic—an additional and equal action being produced, by the return of the particles which were compressed, to their original shape. Consequently, the velocity lost by A, and *that gained by B,* will, each, be *twice* as great as if they were non-

EXAMPLE 1.—Let $A=B$; $V=10$; and $V'=0$. Substituting these values we get

$$v=\frac{0}{A+B}=0$$

$$v'=\frac{20A}{2A}=10$$

A will, therefore, cease to move; and B will move, with the former velocity of A.

EXAMPLE 2.—Let $B=2A$; $V=100$; and $V'=20$.

$$v=-6\cdot666, \text{ and}$$

$$v'=73\cdot333, \text{ \&c.}$$

A will, therefore, after collision, have a negative motion—or one opposite to that which it had before; and B a positive, that is, one in the same direction as that of both A, and B, before collision.

If either body is immovable, it may be considered as infinite.

85. The reason of all these effects will be evident after a little consideration. When a non-elastic body strikes

elastic. Hence the velocities of A and B, after impact, will be expressed, by twice the values which we have found, respectively, for v and v' in the above equations. Therefore, in reality,

$$v=V-2B.\frac{V-V'}{A+B}=\frac{2BV'+(A-B)V}{A+B}: \text{ and}$$

$$v'=V'+2A.\frac{V-V'}{A+B}=\frac{2AV-(A-B)V}{A+B}$$

Since $v=V-2B\frac{V-V'}{A+B}$, and $v'=V'+2A\frac{V-V'}{A+B}$, it follows that

$$v-v'=V-V'-2(A+B)\frac{V-V'}{A+B}=V-V'-2(V-V')=-(V-V')$$

=(if we remove the vinculum)$-V+V'$=(if we transpose) $V'-V$.—That is, (changing all the signs) $V-V'=v'-v$: and $V+v=V'+v'$: or the sum of the velocities of one body, before and after impact, is equal to the sum of the velocities of the other body, before and after impact—the velocity, gained by one body, being lost by the other. It is not to be supposed, however, that the velocity of each body, before and after impact, will be the same, the direction being merely changed; but that the velocity of one will be increased, and of the other decreased, to such an extent, as that they will have the same difference of motion, in the given direction. In the case of A being less than B, it would follow, that A has in some sense communicated to B more motion than it had itself—to the extent to which its own motion has become negative, or in the contrary direction.

another, which is immovable, the motion of the former is destroyed, in compressing the particles of both; and this motion is not restored, since the bodies, from the very nature of non-elasticity, remain compressed, and therefore cannot separate.

86. If a non-elastic body strikes another at rest, but movable, compression of the particles will go on, until the striking body has communicated to that which is struck, enough of force to set it in motion with some common velocity; one body then ceases to act on the other. But, since there is no force to cause their separation, they will move on together.

87. When both bodies are elastic, and one is immovable, compression proceeds, until half the motion is destroyed; the entire force, in an opposite direction, is then given back again to the movable body: on account of both bodies recovering their shape, with exactly the force which caused it to be altered.

88. Hence the effect of a moving body on a fixed plane, when both body and plane are elastic, is twice as great as when neither is so, the velocity and mass being constant; because the plane is then subjected, also, to the equal, and opposite force, restored by elasticity.

89. If one of the elastic bodies is in motion, and the other is at rest, but movable, when they are equal, compression goes on until a common velocity is acquired: that is [81], until the body, at rest, takes away half its motion from the other; then as the same effect is produced by the particles in recovering their former shape as in losing it, the body originally at rest, receives all the remaining motion.

90. But if the striking body is larger than that which is struck, the whole motion of the former will not be expended in moving the latter; the former will, therefore, continue to move, though more slowly.

91. If the body that is struck is the larger, when the whole motion of the smaller will have been communicated, the larger will not have obtained a sufficient velocity to carry it away from the comparatively rapid reaction of the striking body; it partakes, therefore, to a certain extent, of the nature of an immovable body: the effect is modified accordingly; and the smaller body rebounds from it.

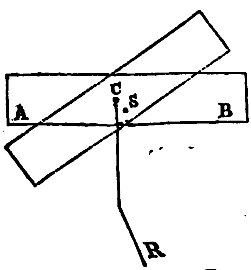
92. If both bodies are in motion, in the same direction, that which is struck, will have its motion accelerated; and the impinging body will have its motion diminished—but to a less extent than before.

93. From what has been said, it may be anticipated that when a number of equal, and perfectly elastic bodies are placed in a right line, and in contact, if the outside one is made to impinge against that which is next it, only the other outside body will move, and with a force equal to that of impact. If they are a decreasing series they will all move; but with an increasing velocity. If they are an increasing series, the striking body, and the others in succession, except the last, will move backwards, and with decreasing velocity; but the last or one most remote from impact, will move forward. In all these cases there are a number of actions and reactions, which, however simultaneous in appearance, are successive in reality.

94. THE CENTRE OF GRAVITY is that point, in a body, at any two opposite sides of which gravity produces equal momenta—the smallness of the number of particles, at any one side, being compensated for, by their greater distance [43] from the centre of gravity. Hence the centre of gravity is that point which being supported, the body will remain at rest. The centre of gravity of a body may or may not coincide with its centre of magnitude—that is, with the centre of its mass. The centre of magnitude is the centre of the particles: but the centre of gravity is the centre of their momenta.

95. If the point by which a body is suspended coincides with the centre of gravity, the body will remain at rest, in all positions; because, in every position, it will have equal and opposite momenta, at both sides of the point of support.

FIG. 6.



96. If a point S, fig. 6, *under* C, the centre of gravity, is supported, there will be "unstable" equilibrium—that is, equilibrium easily destroyed; because the *least change will* remove C from

over its support; and then, its tendency to assume the lowest possible position will not be counteracted. For if the body turns ever so little round S, towards the position indicated by the dotted lines, the centre of gravity will be in the vertical line CR, and will be unsupported; the body will, therefore, revolve.

97. When the point of suspension is *over* the centre of gravity, there will be "stable" equilibrium; because the tendency of the centre of gravity to assume the lowest place, will bring the body, when disturbed, to its former position.

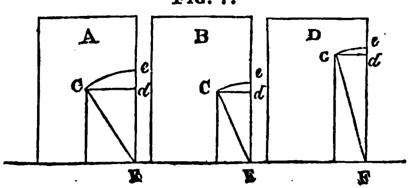
98. A line passing through the point of suspension, and perpendicular to the horizon, is called "*the* line of direction:" and the centre of gravity of the body will always be found, in some part of it. For, when a body, suspended freely, is at rest, the centre of gravity must be supported; which cannot be the case, unless it is directly under or over the point of suspension.

99. If a body is suspended, freely, from two different points in it, and the corresponding lines of direction are drawn, the centre of gravity must be found [98] in *both* these lines; and consequently, it must be at the point of intersection. This, therefore, when the body is very thin, affords, sometimes, a means of discovering the position of its centre of gravity.

100. If the line of direction falls *outside* the base of a body, the latter will overturn; for, the centre of gravity not being supported, motion must ensue.

101. If the line of direction falls *within* the base, the body will be supported, but the nearer it is to the extremity of the base, the more unstable the equilibrium; because the less the height through which the centre of gravity must be raised, in order that the body may be overturned. This will be illustrated by fig. 7. Let C be the centre of gravity of each of the bodies A, B, and D. To overturn any of them, the centre of gravity must describe the *curve Ce, and must*

Fig. 7.



be lifted through the distance *de*—which is evidently increased, by removing the centre of gravity within the body, its height above the base being constant.

102. Raising the centre of gravity in the same line of direction renders it more easy to overturn the body. For the angle *d* F C, fig. 7, is diminished; and, therefore, in the right-angled triangle *d* F C, the hypothenuse and base approach to equality. But it is through the difference between the hypothenuse and base, that the centre of gravity must be raised, if the body is overturned. Hence, the danger of placing a large quantity of luggage on the top of a coach; hence, also, the accidents which occur, from persons suddenly standing up in a boat through fear, &c.

103. It is very difficult to keep a body balanced on a point, or a line—unless a rapid rotary motion counteracts the tendency to fall in one direction, by, after half a revolution, an equal tendency to fall, in the opposite, and these tendencies succeed each other so rapidly that the body, on account of its inertia, has not time [6] to yield to any one of them, before the next begins to operate. The rope dancer avails himself also of the properties of the centre of gravity, to keep up equilibrium by means of a pole [7]: counteracting a tendency to one side by moving the pole towards the other.

104. If two bodies A and B, fig. 8, are immovably connected by a rod supposed to be without weight, their common centre of gravity, when they are

FIG. 8.

in equilibrio, will be at a distance from each, "inversely proportioned to its mass." For if one is twice as small as the other, to render its momentum equal to that of the other, we must make its velocity twice as great as that of the other [74]. But this is effected by removing it to twice as great a distance, from the centre of motion [43].

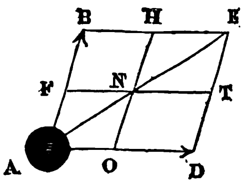
105. COMPOSITION, AND RESOLUTION OF FORCES.—When two, or more forces, combine to produce a single one, they are said to be "compounded;" and that single one is called the "resultant." When one force is decomposed into two, *or more, it is* said to be "resolved." Lines may be

used to represent forces; because they may be drawn proportional to the forces, and in the same directions.

106. If the two forces are in opposite directions, and are equal, it is evident that their resultant will be 0: if they are unequal, it will be their difference. If they are in the same direction, it will be their sum.

107. To find the resultant of any two forces.—"Cause the lines representing the forces—or lines proportional to them, and in the same directions—to form an angle, at the point where they are supposed to act simultaneously; complete the parallelogram, and draw a diagonal between the lines representing the forces: this diagonal will be the required resultant." For, let A, fig. 9, be the body on which forces AB and AD act. Since there is a force acting on A, which, in a given time, would carry it across the line DE, or DE produced, and there is nothing to counteract that force, or any part of it—because there is no force in the opposite direction—the body *must* cross the line DE, or its prolongation. Again, since there is a force acting on the body A, which, in the same given time, would carry it across the line BE, or its prolongation, and there is nothing to destroy that force, or any part of it—there being no force in the opposite direction—the body *must* cross the line BE also, or its prolongation. That is, at the very same moment of time, it will cross both DE and BE; and therefore, at that same moment, it must be found at their intersection E. In a similar way we can prove that it must be found at any other point N, of the diagonal AE. For, from the properties of similar triangles, of which there are four in the given figure (AFN, ABE, AON, ADE), AF, and AO are proportional to AB, and AD. Therefore, the body, for the reasons just given, must cross ON and FN, at the same time; and must, consequently, be found at their point of intersection N.

FIG. 9.

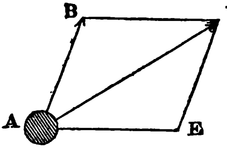


108. When all the sides of any rectilineal figure, except one, are taken, "in succession," to represent the quantity, and direction of forces acting together, the remaining

side, taken in an opposite direction, will represent the resultant.

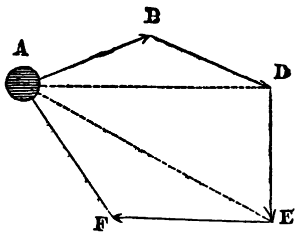
Let the triangle ABD, fig. 10, be the given figure. Let AB and BD be the given forces. Draw AE equal, and paralled to BD; ED equal and parallel to AB:—AE may be used, instead of BD, to represent one of the forces. But [107], the resultant of AB and AE is AD: therefore the resultant of AB and BD is AD.

Fig. 10.



Next, let ABDEF, fig. 11, be the given rectilineal figure; let AB, BD, DE, and EF represent the given forces:—the resultant will be AF. For, draw the lines AD and AE. The resultant of AB and BD is AD: the resultant of AD and DE is AE; and the resultant of AE and EF, is AF. Therefore AF, the remaining side, taken in an opposite direction, represents the resultant of all the forces.

Fig. 11.



109. Hence, briefly, to find the resultant of any number of forces. "Lines are to be drawn, which, joined together, and taken in succession, represent the quantities, and directions of the given forces:—a line completing the figure, will, when taken in the opposite direction, represent the required resultant."

110. It follows that if all the sides of any rectilineal figure, taken in succession, represent the quantity and direction of forces, acting together on a body, the latter will remain at rest: since all the forces but one are equivalent to a force equal and opposite to that one.

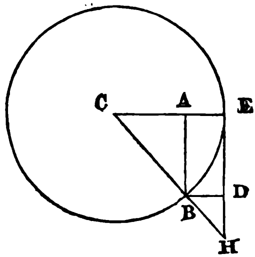
111. Circular Motion.—This is produced by two forces; one of them called *centripetal*,* tends to draw the body "towards" the centre; and the other called *tangential*, is at right angles to the centripetal, being in the direc-

* *Kentron*, a centre; and pětto, I join together. Gr.

tion of a tangent. *Centrifugal** force, which arises from inertia [5], tends to draw the body from the centre:—it is equal, and opposite to centripetal: and both together are called "central forces."

Let EB, fig. 12, be the indefinitely small portion of a circle, which may be considered as a straight line; EA will represent centripetal, and ED tangential force. When these are to each other as EA: ED, EB will be the resultant. If the ratio of the centripetal to the tangential force, is constant, the curve described will be a circle—greater, or less according as EA is diminished, or increased, ED remaining constant; or, as ED is increased, or diminished, EA remaining constant.

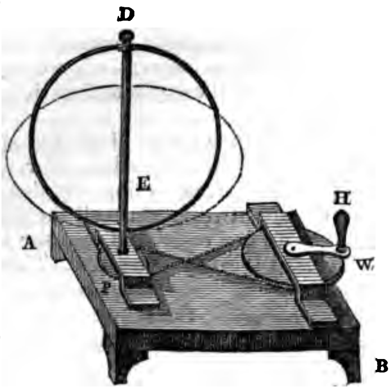
FIG. 12.



The body is supposed to move from D to B, during the time it is passing from E to B: while in reality, it will, in that time, have moved from H to B: since, but for centripetal force, it would be at H, instead of at B. But, since the arc, EB is supposed to be indefinitely small, the figures AEDB, and AEHB, may be considered equal and coincident.

112. Centrifugal force may be illustrated by the apparatus represented, fig. 13. When the handle H, is turned round, the pulley W, by means of the smaller pulley, P, moves the axis, DE, with considerable velocity:—DE carries round along with it, a thin hoop of brass, the upper side of which is capable of

FIG. 13.

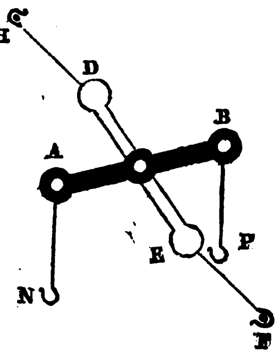


* *Centrum*, a centre; and *fugo*, I fly. Lat.

sliding freely upon it. When the hoop revolves with sufficient rapidity, centrifugal force causes it to assume the form indicated by the dotted lines—the spheroid it then generates, by rotation, being flattened at the poles, and bulged out at the equator. This instrument shows how the revolution of the earth, on its axis, causes it to be an oblate spheroid.* The equatorial diameter of the earth is about 26½ miles greater than its polar. The equatorial diameter of Jupiter exceeds its polar, by 6,000 miles.

113. Centrifugal force is sometimes used to prevent accidents, during descent into mines. The bar AB, fig. 14, is fixed on the axis which carries the drum, &c., to which the bucket is attached, by a rope, &c. As long as the drum revolves, with moderate velocity, the hooks N and P, turning, respectively, on A and B, pass the pins H and F, without touching them. But, as soon as any thing happens, which would cause the bucket to descend with dangerous rapidity, the hooks are thrown out, by centrifugal force: and being arrested by the pins, as represented by the dotted lines, the bucket is immediately prevented from descending further.

FIG. 14.



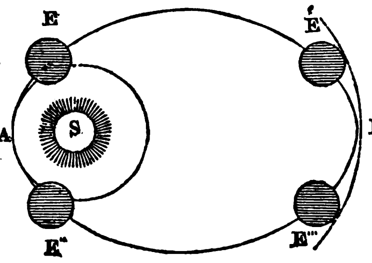
114. Coaches, when passing quickly round a corner, are sometimes overturned, by centrifugal force. Men, horses, &c., running rapidly round a ring, counteract, instinctively, by leaning inwards, the tendency produced by centrifugal force. From the position they assume, it becomes necessary, in order to overturn them, that their centre of gravity should be lifted through a greater height, since it is lowered; and also their line of direction falls on the base [101] at a point farther removed from that, round which their centre of gravity should turn:—but centrifugal force

* The poles of an *oblate* spheroid are flattened, so that it resembles an orange; the poles of a *prolate* spheroid are prominent, so that it is like an egg.

is unable to overcome the increased difficulty. In equestrian exercises, both horse and rider, when the motion is rapid, incline themselves greatly towards the centre of the circle. This is supposed by ignorant persons, to be a proof of skill; but so far from increasing the difficulty of remaining on horseback, it is indispensably necessary to prevent both horse and rider from falling. Sometimes the rider seems, merely, to lie against the horse, with nothing underneath to support him; but the rapid circular motion, generates centrifugal force, sufficient to press him against the horse so strongly, that the friction produced, is quite enough to keep him from sliding down. To prevent railway carriages from being upset, when passing round sharp curves, the outer rail is raised; this inclines the carriage inwards. Centrifugal foree has been applied to the drying of clothes, in a few moments, without compression or heat.

115. Elliptical Motion.—When the centripetal and centrifugal forces have not a constant ratio, the motion produced is in some other figure than a circle. If the centripetal force varies directly as the distance, it will be an ellipse; the centripetal force will tend to the centre of the figure; and the body will, during revolution, twice approach to, and twice recede from, that which attracts it. If the centripetal force varies inversely as the square of the distance, the motion, will, also, be in an ellipse; but the direction of the centripetal force will be towards one focus; and during revolution, the body will once approach to and once recede from, that which attracts it. Since gravity, which varies inversely as the square of the distance, is the centripetal force acting upon the planets, their orbits are ellipses. Let S, fig. 15, be one of the foci of the orbit of a planet, the different positions of which are represented by E, E′, &c.; the tangential force decreases from *A to B; but increases*

Fig. 15.



from B to A. The effect of gravity is greatest at A:—but it cannot draw E to S, nor cause it to describe a circle, since, on account of the velocity, the tangential force, also, is there greatest. Neither does the planet describe a larger curve at B; since the centripetal force, though diminished, has become, at that point, *relatively* great.

116. Kepler found, from observation, that the orbits of the earth, and of all primary planets, are ellipses. Newton showed, from the nature of universal gravitation, and projectile motion, that the orbits, of both primary and secondary planets, must be ellipses. Their paths are, however, disturbed by their mutual actions.

Two kinds of ellipse have been assigned: that of Kepler and Newton, the common ellipse, in which the *sum*, and that of Cassini in which the *product* of the two lines, drawn from the foci to any part of the curve, is constant.

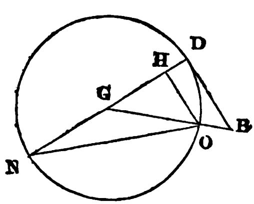
117. The greater the projectile force, the greater the eccentricity of the ellipse. When the projectile force is very great, the curve will not return into itself; and the body will describe a parabola, &c. When the eccentricity is nothing, the curve described is a circle.

118. Centrifugal force is found, by "dividing half the radius, into that height from which the body must fall, to acquire—under the influence of gravity—the velocity of rotation per second: and multiplying the quotient by the product of $32\frac{1}{6}$, and the weight of the body."*

EXAMPLE.—A ball, weighing 15 lbs., and revolving in

* Let t be the time; and let v be the velocity of projection. DB, fig. 16, an indefinitely small space in the tangent, which would be described, with a uniform velocity, will be [45] $=tv$. During this time, the body would recede from C, the centre of the circle, by a space $=$BO; since, by the action of the force of projection, it should have been at B, [111,] when, under the influence of centripetal force, it has been drawn to O:—but as the arc is infinitely small, BO$=$DH. The effect of the centripetal force, since it is uniformly

FIG. 16.



accelerating, would be during the time t [55] $=\frac{Ft^2}{2}$; F being the last *acquired velocity* at the end of 1″. We have seen also that

a circle 3 feet in diameter, makes 100 revolutions per minute: what is its centrifugal force? 100 revolutions per minute $=\frac{100}{60}=1{\cdot}66$ &c., revolutions per second. And since the circle is 3 feet in diameter, its circumference is $3\times3{\cdot}141593=9{\cdot}424779$ feet. Then, $9{\cdot}424779\times1{\cdot}66$, &c. $=16{\cdot}707965$ feet per second. But a body, to acquire that velocity, must [56] fall 3·84 feet. And $\frac{3{\cdot}84}{\frac{R}{2}}=\frac{3{\cdot}84}{0{\cdot}75}:\frac{3{\cdot}84}{0{\cdot}75}\times$ $32\frac{1}{6}\times15=2470{\cdot}4$ lbs.

119. It follows that, when the velocity and radius are constant, the centrifugal force is proportional to the weight.

120. When the radius is constant, the centrifugal force is directly proportional to the square of the velocity.

If the earth were to revolve seventeen times more rapidly than it does, the centrifugal force, at the equator, would be equal to gravity; and a body would not fall there, although

the effect is BO or DH.—Therefore, $\frac{Ft^2}{2}=$DH. But from the nature of the circle, the triangles NDO and OHD are similar:—since they have a common angle; and the angles HOD (=ODB, an angle of the segment: for a small arc and its cord may be supposed coincident; and HO is drawn parallel to DB) and DNO are equal —because each is measured by half the arc DO. Therefore ND: DO::DO:DH$=\frac{DO^2}{ND}=$ (R being the radius of the circle) $\frac{DO^2}{2R}$. But the arc being very small, DO=DB. Therefore DH$=\frac{DB^2}{2R}=$ (because, as we have seen, DB$=t\,v$) $\frac{t^2v^2}{2R}$. But DH has been proved equal, also, to $\frac{Ft^2}{2}$. Therefore $\frac{t^2v^2}{2R}=\frac{Ft^2}{2}$. And $F=\frac{v^2}{R}$. Calling the velocity due to gravity in 1″ (that is, $32\frac{1}{6}$ feet) g; v [57] $=tg$. Therefore, $v^2=t^2g^2=t^2g$ (twice the altitude due [55] to t'') multiplied by g. Calling $\frac{t^2g}{2}$ (the altitude due to t'') a, we have $v^2=ag$. And substituting this value of v^2 in the equation $F=\frac{v^2}{R}$, we have F (the centripetal force corresponding to a unit of the mass)$=\frac{2ag}{R}=\frac{ag}{\frac{R}{2}}$. Multiplying this by the weight, we have the centripetal force of the whole body: and therefore its equal and opposite, the centrifugal.

unsupported. If the centrifugal force were still greater, the water, &c., on the surface of the earth, would be projected into infinite space: and there would be an impassable zone of sterility.

121. When the velocity is constant, the centrifugal force is inversely proportional to the radius.

122. When the number of revolutions is constant, the centrifugal force is directly proportional to the radius.

123. When the radius and centrifugal force are given, to find the velocity and number of revolutions per minute. "Multiply the centrifugal force corresponding to a unit of the weight, by the radius; and divide the product by $64\frac{1}{3}$: this will give the height, from which the body must fall, to acquire the velocity required.* Having obtained this velocity [58], divide it into the circumference, and the quotient will be the time of one revolution:—dividing this quotient into 60, will give the number of revolutions per minute."

EXAMPLE 1.—The weight of a body is 40 lbs.; its centrifugal force is 1,874 lbs.; and the radius is two feet. Required the velocity and number of revolutions. $\frac{1874}{40}=$ 46·85 lbs. is the centrifrugal force corresponding to a unit of the weight. $\frac{46{\cdot}85\times 2}{64\frac{1}{3}}=1{\cdot}456$, is the altitude corresponding to the required velocity. $\sqrt{(2\times 1{\cdot}456\times 32\frac{1}{6})}=$ 9·67 is the velocity corresponding [58] to an altitude= 1·456, and also the required velocity. Then 12·56636 (the circumference)$\div$9·67$=1{\cdot}3''$ the time of one revolution. And $\frac{60}{1{\cdot}3}=46$, nearly, is the number of revolutions per minute.

EXAMPLE 2.—The radius is 3 feet; and the centrifugal force is equal to the weight; what are the velocity and number of revolutions? Since the centrifugal force and weight are equal, the amount of the former, corresponding to a unit of the latter is 1 lb. But $\frac{1\times 3}{64\frac{1}{3}}=0{\cdot}0466$. And

* $F=\frac{2ag}{R}$ [118; note]. Therefore $FR=2ag$; and $a=\frac{FR}{2g}$.

$\sqrt{(2\times 0{\cdot}0466\times 32\frac{1}{6})}=1{\cdot}73$, is the velocity. $18{\cdot}849558$ (the circumference)$\div 1{\cdot}73=10{\cdot}8957$. And $60\div 10{\cdot}8957 =5\frac{1}{2}$, is the number of revolutions per minute.

EXAMPLE 3.—Let the cohesive power of cast iron be 20 tons per square inch of section: what must be the velocity and number of revolutions, per minute, of a fly-wheel, the diameter of which is 30 feet, the section 64 inches, and the weight of the cast-iron rim 25 tons: so that it shall burst asunder? The entire centrifugal force required will be $64\times 20=1280$ tons. The centrifugal force corresponding to a unit of the weight will be $\frac{1280}{25}=51{\cdot}2$ tons$=114{\cdot}688$ lbs. $\frac{114688\times 15}{64\frac{1}{3}}=26741$, nearly. $\sqrt{(2\times 26741\times 32\frac{1}{6})}=1311{\cdot}6$. $94{\cdot}24779$ (the circumference)$\div 1311{\cdot}6=0{\cdot}0718$. And $\frac{60}{0{\cdot}0718}=835{\cdot}7$ revolutions.

124. When the velocity, radius, and entire centrifugal force are given, to find the weight.—"Find the unit of centrifugal force, corresponding to the given velocity and radius [118]; and divide it into the entire centrifugal force."

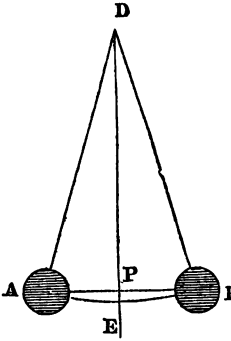
EXAMPLE.—A fly-wheel 7 feet in diameter, making 20 revolutions per minute, has the same centrifugal force as one of 6 tons, 12 feet in diameter, and making 30 revolutions per minute: what is its weight? The centrifugal force of the latter fly-wheel is [118] $795885{\cdot}074422$ lbs. nearly. The centrifugal force corresponding to a unit of the mass of the former is $15{\cdot}352718$ lbs., and $\frac{795885{\cdot}074422}{15{\cdot}352718}=51840$ lbs., nearly, or 23 tons 2 cwt. 3 qrs. 12 lbs.

125. There are many examples of the application of centrifugal force to manufactures, &c. By means of it, the flour is thrown from the rim of the revolving mill-stone. It causes the air to pass, in a strong blast, from the vanes of the winnowing, and blowing machines. It is, as we shall see, the principle of the centrifugal pump, &c.

126. THE CONICAL PENDULUM consists of two balls A and B, fig. 17, attached, respectively to the rods AD, and BD, turning on centres at D, and revolving on the axis DE.

They will describe a cone; and centrifugal force will cause them to fly asunder, when the time of one revolution $= \sqrt{DP} \times 1{\cdot}10784$.* Hence to find the length of DP, with pendulums intended to make a given number of revolutions, before they begin to fly asunder. "Divide the time of one revolution by 1·10784; and the square of the quotient will be the length of DP in feet."

FIG. 17.



EXAMPLE.—What must be the length of DP, in feet, with pendulums intended to make 48 revolutions per minute, without flying asunder? The time of

* The velocity of each ball will be the circumference of the base of the cone, multiplied by the number of revolutions per second:—or, which is the same thing, divided by the time of one revolution. That is, if t is the time of one revolution, and V is the velocity—

$$V = \frac{2PA \times 3{\cdot}141593}{t} \text{ and } V^2 = \frac{PA^2 \times (3{\cdot}141593)^2}{t^2}$$

But [118; note] the centrifugal force is equal to the square of the velocity divided by the radius. Therefore—calling the centrifugal force C,

$$C = \frac{4PA^2 \times (3{\cdot}141593)^2}{t^2} \div PA.$$

But each of the balls is acted on by three forces—gravity, centrifugal force, and the tension of the rods; which may be represented, respectively, by DP, PA, and AD. Therefore,

Gravity : Centrifugal force :: DP : PA. That is

Gravity : Centrifugal force :: cos. ADP : sin. ADP

or, in other words, as the vertical distance of the balls from D, is to their horizontal distance from P. Substituting for centrifugal force, its equal, we have Gravity : $\frac{4PA^2 \times (3{\cdot}141593)^2}{t^2} \div PA :: DP :$ PA. Therefore (multiplying the means and extremes) gravity $\times PA = \frac{4PA^2 \times (3{\cdot}141593)^2 \times DP.}{t^2 \times PA}$ And $\frac{\text{gravity} \times t^2}{4 \times (3{\cdot}141593)^2 PA} = \frac{DP}{PA}$.

Therefore $t^2 = \frac{DP}{PA} \times \frac{4 \times (3{\cdot}141593)^2 \times PA}{\text{gravity}} = \frac{DP \times 4 \times (3{\cdot}141593)^2}{\text{gravity}} =$

$\frac{DP}{\text{gravity}} \times 4 \times (3{\cdot}141593)^2$. And $t = \sqrt{\frac{DP}{\text{gravity}}} \times \sqrt{[4 \times (3{\cdot}141593)^2]} =$

one revolution is $\frac{60}{8}=1{\cdot}25''$. And $\left(\frac{1{\cdot}25}{1{\cdot}10784}\right)^2=1{\cdot}13$ feet$=13\frac{1}{2}$ inches nearly.

127. To find the number of revolutions, when DP is given.—"Multiply the square root of DP, in feet by 1·10784:—the quotient will be the time of one revolution: divide 60 by this quotient, and the result will be the number of revolutions per minute."*

EXAMPLE.—What number of revolutions will be made by pendulums, DP being 30 inches? 30 inches=2·5 feet.

$$\frac{\sqrt{2{\cdot}5}\times 1{\cdot}10784}{60}=34 \text{ revolutions, nearly.}$$

128. Since 1·10784 is invariable, "the periodic time is proportional to the square root of DP."

EXAMPLE.—When DP=30 inches, the number of revolutions is 34; what will the number be, when it=24? —When DP=30, the periodic time is $\frac{60}{34}=1{\cdot}76$. Then $\sqrt{30}:\sqrt{24}::1{\cdot}76:\frac{\sqrt{24}+1{\cdot}76}{\sqrt{30}}=1{\cdot}574$, is the time of one revolution, when DP=24. And $\frac{60}{1{\cdot}574}=38$, nearly, is the number of revolutions per minute. As the balls diverge, the $\sqrt{\text{DP}}$ decreases; hence, to produce further divergence, the velocity of rotation must be increased.

129. Bodies have a tendency, when revolving, to turn round on their shorter axis: which, therefore, will sometimes assume a certain position in opposition to gravity.

(since gravity [55; note] is represented by $32\frac{1}{6}\frac{\sqrt{\text{DB}}}{\sqrt{32\frac{1}{6}}}\times\sqrt{[4\times(3{\cdot}141593)^2]}=\sqrt{\text{DP}}\times 1{\cdot}10784$. That is, the square root of the perpendicular distance DP, fig. 17, multiplied by 1·10784.

When ADP=45°, centrifugal force=gravity; for DP=PA.

Since $t=\sqrt{\text{DP}}\times 1{\cdot}10784$, $\sqrt{\text{DP}}=\frac{t}{1{\cdot}10784}$; and $\text{DP}=\left(\frac{t}{1{\cdot}10784}\right)^2$. —That is, the length of DP, for any number of revolutions, is equal to the square of the quotient, obtained by dividing 1·10784 into the time of one revolution.

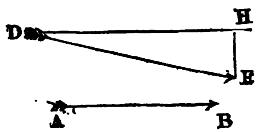
* We have seen [126; note] that $t=\sqrt{\text{DP}}\times 1{\cdot}10784$. But $\frac{60}{t}=\frac{60}{\sqrt{\text{DP}}\times 1{\cdot}10784}$ is the number per minute

130. When bodies revolve, it must be about their common centre of gravity; for we may suppose that the centripetal force is derived from, and its quantity influenced by, the distance from this point:—besides there would not otherwise, be equal and opposite momenta at all opposite sides, and the centre of gravity could not retain its position.

131. If two bodies revolve about a third, it is in reality, their common centre of gravity that revolves; because it is at that point the force of projection may be supposed to be concentrated. The centre of gravity of the earth and moon is 6,000 miles from the former:—hence the earth is 12,000 miles nearer to the sun at full, than at new moon. The centre of gravity of the sun, earth, and moon is within the sun. The sun moves round this common centre of gravity.

132. To find how much of any force DE, fig. 18, is efficient in a given direction AB.—"From the commencement D, of the line representing the given force, draw DH parallel to the direction of the required force; and from E, the extremity of the line representing the given force, draw EH perpendicular to DP." DH will represent the amount of the force DE, which is efficient in the direction AB.

FIG. 18.



133. Should the perpendicular fall on DH, produced *backwards* from D, the given force, is not only inefficient in the required direction, but contains a force exactly opposite to it.

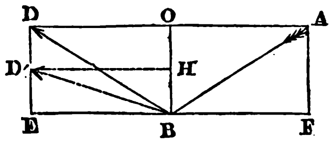
134. The perpendicular HE, represents a force, wholly without effect in the required direction; since it cannot be so resolved as to produce a force, either in the same direction, or in the opposite. To render DH effective, HE must be destroyed by an equal and opposite force.—"Resolution, therefore, is reducible to 'composition' of forces;" since we may suppose two forces DE, and EH (the latter being the force which neutralizes HE) to produce [107] DH, as their resultant. And the real question is, not what *part of DE is* effective in the direction AB, but what

force, along with DE, would produce a force in that direction.

135. It is evidently more economical to use a single force than the resultant of two or more:—for the resultant can never be equal to the sum of the forces which produce it; since, however many of the sides of the rectilineal figure [108] representing the forces employed, only one of them can represent the result ınt.

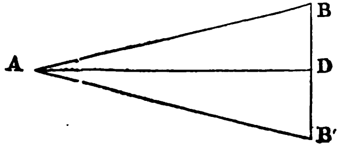
136. The laws which govern the composition and resolution of forces, enable us to show that a body striking a plane, will be reflected from it, at an angle depending on the amount and direction of the original force, and on the elasticity of the plane, and of the body. Let AB, fig. 19, represent the quantity and direction of the force, with which a body impinges against the plane EF. Let this force be resolved into AO parallel, and OB, perpendicular to EF. When the body reaches the plane, it will be acted upon by two forces, one represented by BE=AO; and the other, if the plane is perfectly elastic, by BO=OB: or, if it is not perfectly elastic, by some force BH, less than OB. The resultant of BE and BO will be BD=BA; and making the angle of reflexion DBO=the angle of incidence ABO. The resultant of BE and BH would be BD′, which is less than BD; and the angle of reflexion D′BH, would be greater than the angle of incidence ABH. Some writers consider ABF and DBE as the angles of incidence and reflexion; they also are equal, being the complements of equal angles.

Fig. 19.



137. These principles show the importance, which should be attached to the "line of draft," in vehicles; and that its direction must be, theoretically, such as will cause the pull to be parallel with the intended motion. Let the direction, in which the force is ap-

Fig. 20.

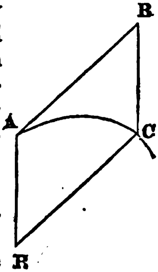


plied, be represented by AB, fig. 20; the intended direction of the body being AD. AB may be resolved [132] into AD, which is in the required direction, and DB, which is expended in lifting the load. We shall find hereafter, that a certain quantity of force in the direction DB, is not useless.

138. If the pull is in the direction AB′, it is resolvable into AD, in the direction of the intended motion, and DB′, which depresses the load, and, therefore, increases its pressure, and, by consequence, the draft.

139. The path of a projectile is a parabola.* Let a body be projected from A, fig. 21, with a force, that, in a given time, would carry it to B; while, in the same time, it would fall, under the influence of gravity, from B to C. AB (since it represents a uniform force—that of projection [45], $\propto t$; and $AB^2 \propto t^2$. But [50] BC (since it represents gravity) $\propto t^2$. Therefore $BC \propto AB^2$. And, since BC=AR; and AB=RC, $AR \propto RC^2$. That is, the abscissa varies as the square of the ordinate: which is found to be the property of the parabola.

FIG. 21.



140. The calculated, and the actual path of a projectile are, on account of the resistance of the air, extremely different. A musket ball, having an initial velocity of 1,700 feet per second, has an actual range of only about half a mile; while, by calculation, it should have a range of 17 miles. When the velocity is more than about 1,340 feet per second, the air cannot rush in behind with sufficient rapidity; which causes a partial vacuum: and thus adds a resistance of nearly 15 lbs. to the square inch. A ball

* A parabola is one of the five conic sections:—which are, the *triangle*, formed by the outline of a section, passing through the vertex and any part of the base; the *circle*, by the outline of a section parallel to the base; the *parabola* of a section parallel to the side; the *ellipse* of an oblique section through both sides; and the *hyperbola*, of a section making a greater angle with the base than the side.

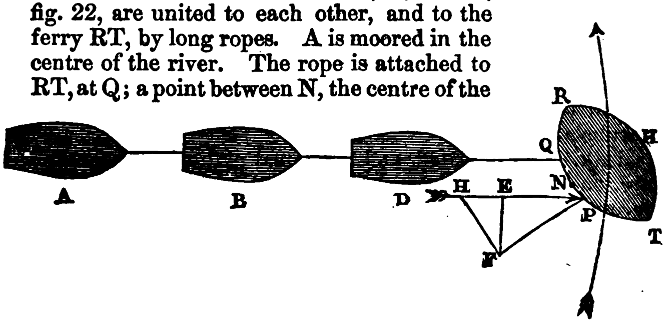
The triangle and circle are not, generally, considered as conic sections.

36 lbs. weight, and $6\frac{1}{2}$ inches in diameter, moving 1,600 feet per second, meets with a resistance, from the air, of about 417 lbs. Adding to this $478\frac{1}{2}$ lbs., the resistance arising from the partial vacuum behind, we shall find that the total resistance is nearly 900 lbs.

141. There are many examples, both of the composition, and resolution of forces, besides those already noticed. The united action of two forces, the one tending to draw the water from the poles to the equator, the other to carry it from east to west—on account of its having a less velocity than the parts of the earth over which it passes—must necessarily produce a tidal current in an intermediate direction [18.]

142. Flying bridges, so common on the rapid rivers of the Continent, consist of boats moved by the stream; and afford a very convenient mode of bringing passengers, horses, carriages, &c., across without any labour on the part of the boatmen. A number of boats A, B, and D, fig. 22, are united to each other, and to the ferry RT, by long ropes. A is moored in the centre of the river. The rope is attached to RT, at Q; a point between N, the centre of the

FIG. 22.



side, and R one end. The force of the stream, represented by HP, is resolved into FP, perpendicular to the side of the boat—consequently [76] effective; and HF, at right angles to FP. FP is resolved into FE, which brings the boat, from one bank to the other, and EN at right angles to FE. When the rope Q is moved to a point between N and T, the boat crosses the stream in the opposite direction. The Po is passed in this way near Rovigo, with great facility.

143. A boat drawn by horses, along a canal, is an example of the composition of forces. The current acting on

the rudder, and the draft of the horses, producing a resulting motion along the canal.

144. SOURCES WHENCE FORCE IS GENERALLY DERIVED. —We obtain force from water, air, steam, animal strength, &c. Water and steam will be considered hereafter.

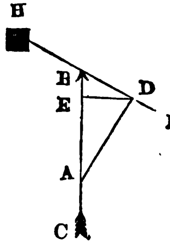
We obtain force from air, by the windmill, or some analogous means. The windmill is used, very extensively, in Holland, to work pumps for drainage—a large portion of the country being under the level of the sea. The sails may be variously arranged:—those which are attached to arms lying in a vertical plane, are the most common. The full effect of the sails is produced, when the plane of the arms which carry them, is perpendicular to the direction of the wind. This position is secured by various contrivances: sometimes by a lever; at others by a *wind vane*, fixed to the movable cap of the mill, but projecting some distance from it, on the side opposite to that at which the sails are placed—the plane of the vane being perpendicular to that of the arms. The vane is moved by the wind, whenever it blows in any direction, except that which is perpendicular to the great sails; and by revolving, works a pinion, which carries the movable cap round on the mill-house, until the plane of the sails is perpendicular to the direction of the wind—which has then no action whatever on the vane. The angle made by the plane of each sail with the plane in which the arms lie, is of great importance; and has formed the subject of much inquiry. If the wind were to act perpendicularly on, or parallel to, the plane of the sail, the latter would have no tendency to revolve. The plane of the sail must, therefore, occupy some intermediate position. This position—or the angle made by the plane of the sail with the direction of the wind—is called the "weather of the sail." It is greatest near the centre of motion; for the greater the velocity of a given part of the sail, the less the effect which the wind has on it, since the smaller the difference between their speeds; hence, we are obliged to increase the action of the wind on the distant parts of the sail which, on account of their greater velocity, withdraw themselves, as it were, from its influence. This is effected by causing the wind to act, in a direction nearer to the perpendicular. The angle of weather,

for any part of the sail, is found by the formula of Maclaurin. According to this, a being the velocity of the wind, and c that of any given part of the sail, the effect of the wind on that part will be a maximum, when "the tangent of the angle of the winds' incidence, or the sails' inclination to the axis, is to the radius, as $\frac{\sqrt{(2+9c^2)}}{4a^2}$, is to 1."

There are in Ireland, undoubtedly, many places, where windmills might be used with as much advantage as in other countries; and they may be constructed on the small scale at a trifling expense.

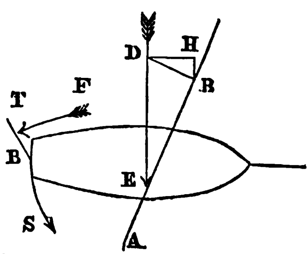
145. The action of the wind on the sail of a windmill, may be understood from fig. 23. Let its direction and amount be represented by CB; let HF be a section of the sail, and of the arm which carries it. AB may be resolved into AD perpendicular to the plane of the sail—and therefore effective, and DB parallel to it—and therefore entirely without effect. Since AD is not tangential, all of it is not effective in producing rotary motion [111]; and it is to be resolved, into ED, tangential, and AE, at right angles, to ED. If, therefore, AB represents the force of the wind, ED will represent that part of it, which causes the sails to revolve.

Fig. 23.



146. The wind DE, fig. 24, acting on the sail of a ship, will impel it in any direction DH, not exactly opposite to that of its own motion. DE may be resolved into DB, perpendicular to the plane of the sail, and therefore effective; and BE parallel to the plane of the sail—and ineffective. DB may be resolved into DH, which is in the direction of motion—and therefore effective; and HB, perpendicular to DH, and tending merely to move the vessel round, but

Fig. 24.



counteracted by the stream flowing along the side, and acting on the rudder.

147. A vessel will not steer, unless its velocity is sufficient to produce a current against the rudder. Hence, even in storms it is necessary to keep up *some* sail, or the ship would not be under command. And when a steamer, going down the Rhone, Rhine, and other rapid rivers, stops at the different towns along the banks, the bow is generally turned *up* the stream; that, when starting, the current, striking on the helm, may render the vessel manageable. Without this, it would drift down the stream, until it should acquire a certain velocity.

148. Animals produce very different effects, in different circumstances. The greater their velocity, the less resistance they can overcome, and *vice versa*. Their motion may be so rapid that they will be able to carry only themselves; or they may move so slowly, that no work will be done. The useful effect lies between these extremes. Animals work best, when their efforts are not constantly the same; also, when they are allowed to rest occasionally.

149. It is calculated that a man will walk, unburdened, $4\frac{3}{4}$ feet per second (or about $3\frac{1}{4}$ miles per hour) for 10 hours per day. Taking his weight at 140 lbs., he will have carried 23,940,000 lbs. a distance of 1 foot. He will carry $85\frac{1}{2}$ lbs. on his shoulders $2\frac{1}{5}$ feet per second, for 7 hours per day. This, neglecting his own weight, will be 4,740,120 lbs. carried 1 foot. He will ascend steps unburdened, at the rate of $\frac{12}{25}$ feet per second, for 8 hours per day.—Taking his own weight at 140 lbs. he will have raised 1,935,360 lbs. 1 foot high, or about the $\frac{1}{12}$th part of what he carried on a horizontal plane. A man has been found to lift about 1,224,000 lbs. 1 foot high, in a day, working on the whole for 5 hours, but working, and resting, alternately.

150. A horse, walking at the rate of about $3\frac{1}{2}$ feet per second, will carry 256 lbs., for 10 hours per day. That is, neglecting his own weight, 32,256,000 lbs. carried 1 foot; or about six times as much as a man, doing the same kind of work. Moving with double the velocity, he will carry 171 lbs. *for* 7 *hours* per day: which is, 30,164,400 lbs. *carried 1 foot.* A horse that will carry 864 lbs. will draw *with a force,* equal only the $\frac{1}{6}$th part of that weight. In ex-

amining the amount of animal power, we can, of course, obtain only approximations:—for, different men, &c., will perform different quantities of the same kind of work; and those who are used to it, will do more than those who are not.

151. The effects produced, vary with the kind of work. According to Buchanan, the exertions of a man in working a pump, turning a winch, ringing a bell, and rowing a boat, are as the numbers 100, 167, 227, and 248.

CHAPTER II.

The Mechanical Powers, 152.—The Lever, 156.—Application of the Lever to the Measurement of Weight, 162.—Combinations of Levers, 177.—The Pulley, 178.—Combinations of Pulleys, 181.—The Wheel and Axle, 191.—The differential Axle, 192.—Examples of the Wheel and Axle, 194.—Combinations of Wheels and Axles, 195.—Different kinds of Wheels, 199.—Teeth of Wheels, 208.—The Inclined Plane, 224.—Descent of Bodies down Planes and Curves, 230.—The Wedge, 237.—The Screw, 241.—Application of the Screw to various purposes, 245.

152. THE MECHANICAL POWERS.—There are two ways, in which the momentum, which is at our own disposal, may be altered, by the modification of its elements. We may change the relative amounts of the velocity and the mass [74] either by increasing the former, and diminishing the latter: or by diminishing the former, and increasing the latter. This change is effected by what are called "the mechanical powers." Since the momentum itself is not altered, we can, at once, compute the effect of these powers, or of any combination of them, however complicated, if we know the *relative* velocity of the power and weight. For, "the power multiplied by its velocity, is equal to the resistance multiplied by its velocity." This, which is called the principle of *virtual velocities*, is one that should never be lost sight of, in mechanics. Were it always remembered, much time, vainly expended by ingenious persons, in seeking for what is called the "perpetual motion," would be saved:—since, the province of machinery is not to *create* momentum, but to *modify* its elements. And

were it possible to construct an infinitely perfect machine, we should receive from it, only that amount of motion which we imparted to it. But the very best we can form, consumes *some* power, and the amount destroyed, is dependent, in a great degree, on its complication. We are to conclude, therefore, that machinery should never be used, except where it cannot be avoided; and that, when used, it should be as simple as possible.

153. To exemplify the principle of virtual velocities, let us suppose that, with a certain machine, the resistance moves through 100 times less space than the power. The momentum of both being equal, the mass of the former must be 100 times the mass of the latter.

154. Whatever causes motion is called a *power*, or *prime mover*. The power may be considered, as so many pounds *falling* through a certain space; and the resistance, or work to be done, as so many pounds *to be raised* through a certain space. We shall designate the power by P; the resistance or weight by W; and the fulcrum* or point of support by F.

155. There are six mechanical powers, reducible to two:—the *lever*—which being modified, gives rise to the *pulley*, and the *wheel and axle*; and the *inclined plane*—from which are derived the *wedge*, and the *screw*. The laws which govern the lever, and the inclined plane, being well understood, those belonging to the rest, are comprehended without difficulty.

156. THE LEVER is a rod, supposed to be inflexible, and without weight. It is of two kinds:—that with equal, and that with unequal arms. The latter may be subdivided into that which has the fulcrum, between the power and weight; and that which has the fulcrum at one end—the power, or weight, being at the other. A lever "of the first order," or that which has the fulcrum between the power and weight may be used to increase either the mass, or the velocity, of the weight. A lever "of the second order," or that which has the fulcrum at one end, the power being at the other, can increase only the mass of the weight. And a lever "of the third order," or that which has the fulcrum

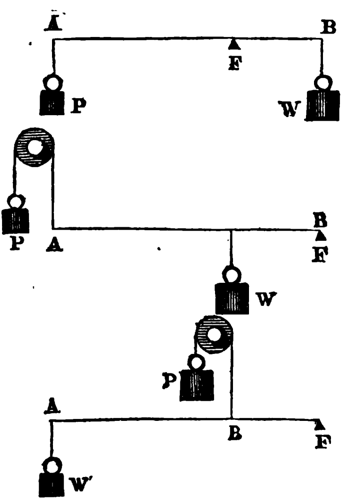
* *Fulcrum*, a prop. Latin.

at one end, the weight being at the other, can increase only the velocity of the weight.

157. The lever with equal arms alters neither mass, nor velocity; but it enables us to change the direction, at which the power acts.

158. Whatever may be the kind of lever, "the power and weight are inversely proportional to the lengths of the arms connected with them." For, calling the velocity of the power V; and that of the weight V′. $PV = WV'$. But, as the velocities of the power, and weight, are proportional to the spaces, which would be described by them—were they put in motion; and [43] these spaces are proportional, to the distances of the power and weight from F, fig. 25, the centre of motion; we may substitute these distances for V, and V′; and the above equation then becomes $P \times AF = W \times BF$. That is, the power multiplied by the length of the arm which carries it, is equal to the weight multiplied by the length of the arm which carries it. And, forming this equation into a proportion, $P:W::BF:AF$.

FIG. 25.



159. Hence, for example with a lever, having the arm which is connected with the power, seven times as long as that which is connected with the weight; the mass of the weight, will be seven times as great as the mass of the power: but the power will move through seven times as much space.

160. The velocity, or mass, of the power, or weight may *be found from the* above equation.

Example 1.—Let $P=50$; $W=472$; and, the velocity

of the weight=3. What must be the velocity of the power, to produce equilibrium?

$$P \times AF = W \times BF. \text{ Therefore}$$

$AF = \frac{W \times BF}{P}$; and substituting the given values,

AF, or the velocity of the power $= \frac{472 \times 3}{50} = \frac{1416}{50} = 28{\cdot}32.$

Example 2.—Required the weight which, at 7 feet from the fulcrum, will balance 8756 lbs., at 4 feet from it.

$$P \times AF = W \times BF. \text{ Therefore}$$

$P = \frac{W \times BF}{AF}$: and substituting the given values,

$$P = \frac{8756 \times 4}{7} = 5003{\cdot}4286.$$

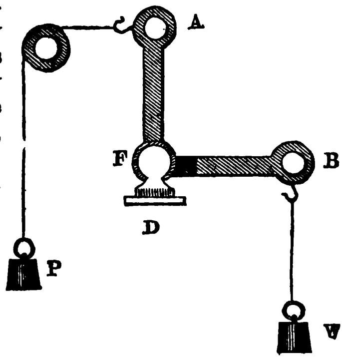
Example 3.—What must be the respective lengths of arms, carrying the power and weight, with a lever of the first order 5·73 feet long; the weight being 84 lbs., and the power 23 lbs.? Call the arm which carries the weight x; the other will then be $5{\cdot}73 - x$. And $x \times 84 = (5{\cdot}73 - x) \times 23$. Solving this equation, we find $x = 1{\cdot}23$ nearly; and $5{\cdot}73 - x = 5{\cdot}73 - 1{\cdot}23 = 4{\cdot}5$. The arms, therefore, should be, respectively, 4·5, and 1·23.

Example 4.—Let the length of a lever, of the first order, be 14 inches; required the lengths of the arms, so that, while the power moves 1·75 inches, the weight may move 4·32 inches? x being the length of the arm which carries the weight, that of the arm which carries the power will be $14 - x$. The spaces described by the power and weight are [158] as the arms which carry them. Hence $1{\cdot}75 : 4{\cdot}22 :: 14 - x : x$ and $1{\cdot}75\, x = (14 - x) \times 4{\cdot}32$. Solving this equation, we find $x = 9{\cdot}963$; and $14 - x = 14 - 9{\cdot}963 = 4{\cdot}037$. The respective lengths of the arms must, therefore, be 9·963, for that which carries the weight; and 4·037, for that which carries the power.

161. It is not necessary that the arms of the lever should be in a right line. They may, as in fig. 26, form an angle, when the directions in which the power and weight act are not parallel. This species of lever follows the same law as the rectilinear. For, rotation round F, is the effect to be produced; and, of the two forces required for this purpos

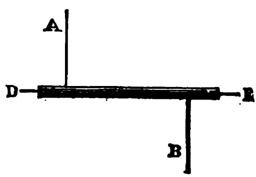
[111], the centripetal is supplied by the lever itself, and the tangential by the power: the result is the same, whatever may be the radii to which the directions of the power, and weight, are, respectively, perpendicular, and attached—provided these radii are immovably connected.

Fig. 26.



Neither is it necessary that the arms should move in the same plane: thus they may be A and B, fig. 27, moving round along with the rod DE, which turns on centres D and E.

Fig. 27.



162. Application of the Lever to the Measurement of Weight. *The ordinary scales*, for weighing merchandize, is an example of the lever with equal arms. For, since the power and weight are intended to be equal, the arms also [74] must be equal. We can ascertain, whether or not, the arms are of the same length, by accurately counterpoising two bodies in the scales to be tested, and then changing them from one scale to the other. If equilibrium still remains, the arms are equal—since, it is evident, that the power multiplied by the length of either arm, will be equal to the weight multiplied by the other.

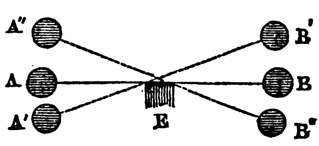
163. If the arms are not equal, the real weight of any body may be found, by weighing it in each scale, multiplying together the weights thus obtained, and taking the square root of the product.*

* For, let a represent the article to be weighed; let b and c be the unequal arms of the balance; let x be the weight of the body, when suspended from b; and y its weight, when suspended from c. *In the former case*, from the nature of the lever, we have $a \times b =$

164. The position of the point of suspension, in a balance, is a matter of importance. It may be under, over, or coincident with the centre of gravity of the beam. If it *coincides* with it, the weights in the scales may be equal, and yet the beam [95] may not be horizontal: which would be inconvenient, as it is from the horizontality of the beam we judge that the weight, and the substance to be weighed, are equal. If it is *under* the centre of gravity, the equilibrium, obtained with equal weights, [96] would be unstable. The point of suspension must, therefore, be immediately *over* the centre of gravity of the beam. The nearer the centre of gravity is to the point of suspension the slower the balance will oscillate; since gravity will be the less effective; but it will be the more easy to put it in motion. Hence slowness of oscillation is a proof of delicacy. If the points, from which the pans are suspended, are above the centre of suspension, the more the balance is loaded, the more its sensibility is increased, since the centre of gravity is raised: but the latter may, at last, coincide with the point of suspension, and the balance will then cease to act. If they are below the centre of suspension, adding weights diminishes the sensibility, by lowering the centre of gravity. The balance is independent of the load, when the three points of suspension are in a right line which is a little above the centre of gravity. Loading the scales then increases the sensibility, by raising the centre of gravity—which can never be quite so high as the centre of suspension. The sensibility will, however, be decreased by friction to the same extent, that it is increased by raising the centre of gravity.

165. The fulcrum of a balance should be as thin as possible:—in well constructed balances, it is a knife-edge, of hard steel, playing on agate, and raised up when not in use, lest its sharpness should be impaired. If the fulcrum is not thin, the

FIG. 28.



$x \times c$: and in the latter, $a \times c = y \times b$. Multiplying the corresponding terms in the two equations, we get $a^2bc = xybc$; then, dividing both by bc, $a^2 = xy$; and $a = \sqrt{xy}$.

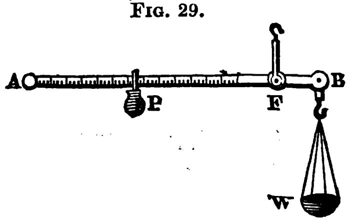
arms of the balance are not always equal in length. Let AB, fig. 28, be a lever, resting on a thick fulcrum E, the arms being equal. If it assumes the position A′B′, there will be a difference between the lengths of the arms, equal to the width of E. In the position A″B″ the arms are also unequal, to the same extent.

166. The greater the angle through which a balance moves, with a given weight, the more sensitive it is. Lengthening the beam increases the sensitiveness, by causing the preponderating weight to act with a greater leverage.

167. In philosophical experiments, the weights should be as accurate as possible; and, to prevent them from being altered by corrosion, the smaller ones, at least, ought to be made of platinum. They should be moved from one place to another with a forceps, that they may not be affected either by moisture, or change of temperature. Troy weight is generally used; as there is an exact number of grains in the troy ounce. When the barometer stands at 30 inches, a cubic inch of distilled water, having a temperature of 62°, weighs 252·458 grains.

168. *The Steel Yard*, fig. 29—sometimes called, from a misconception, the Roman* "balance," has the fulcrum F, and the hook to which the scale, &c., containing the substance to be weighed, is attached, fixed permanently. The weight P, is movable; and according to its place—ascertained by a graduated scale—the arm which carries it is practically, longer, or shorter. The two arms AF and BF, being counterbalanced, may be considered without weight.

Fig. 29.

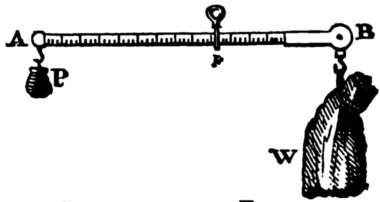


169. *The Danish Balance*, fig. 30, differs from the steel

* Its name is said by some to be derived from *Romman*, an eastern word, signifying the pomegranate; and to have been suggested by the shape of the weight employed.—We have, however, seen this kind of balance used more commonly in Rome than in any other *place.*

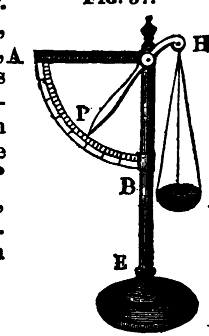
yard, by having the points, to which the weight and counterpoise are attached, fixed—the fulcrum F being movable, so as to alter the relative lengths of the arms.

FIG. 30.



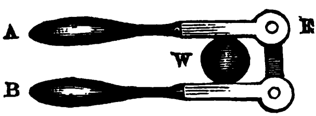
170. *The bent lever balance*, fig. 31, is so contrived that, the fulcrum, counterpoise, &c., remaining the same, the amounts of very different weights may be ascertained. Its action depends on the fact that, in proportion as H is depressed, by loading the scale E, the leverage of the counterpoise P —which also acts as an index—and, consequently its efficiency is increased. The weight of a body in E is shown on the graduated arc AB by P.

FIG. 31.



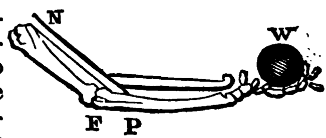
171. *The Nut-cracker*, fig. 32, is an example of the lever, which has the power at one extremity A, and the fulcrum F, at the other: the resistance W, being between both.

FIG. 32.



172. *The human arm*, fig. 33, is an example of the lever having the power between the fulcrum and resistance. NP is the muscle, acting at P; the elbow F, is the fulcrum: and the weight W, is supported by the fingers. The seeming inconvenience of such a lever, is more than counterbalanced, by the compactness which it gives to the arm; and, although the muscle, on account of it, requires greater power, no force is, in reality, lost.

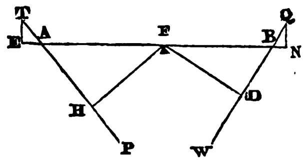
FIG. 33.



173. The common *claw hammer*, used to draw nails, is an example of the angular lever. Also, the *bell-crank* [161], so common in machinery.

Many other instances of the application of the lever, to useful purposes, will suggest themselves.

FIG. 34.



174. When the power and weight, or either of them, does not act perpendicularly on the arms of the lever, P : W : : FD, (a perpendicular to BW, the direction of W): FH (a perpendicular to AP, the direction of P).*

175. If the power, or weight, does not act perpendicularly to the arm which carries it, it becomes less effective:—but no force is lost, since the space, described by the power, or weight, is proportionably diminished. Thus, were the power to act perpendicularly to AF, fig. 34, it would be more effective, but more force would be consumed, since the space described would be the arc of a circle the radius of which is AF. When the power acts perpendicularly to FH, it is less effective; but less force is consumed, since the space described by the power is the arc of a smaller circle, the radius of which is FH. Many mistakes are made regarding the *crank*—a species of lever we shall examine hereafter—from this fact not being well understood.

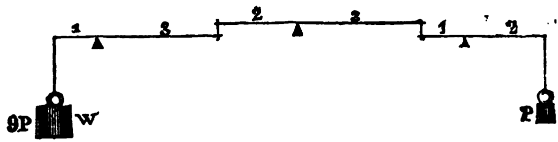
176. With every kind of lever, "the power multiplied by a perpendicular from the fulcrum to the direction of the power, is equal to the weight multiplied by a perpendicular to the direction of the weight." When the power, and weight, act perpendicularly to the arms which carry them,

* For, produce AP to T. Let TA represent the quantity and direction of the power; and resolve it into TE, tangential to AF—and therefore effective, and EA, parallel to AF—consequently ineffective. In the same manner, produce BW to Q; and resolve QB, representing the quantity and direction of the weight, into QN, effective, and NB ineffective. Then [158] AF×TE=BF×QN. But, as the triangles TEA and FHA, QNB and FDB are similar, TA : AF : : TE : FH. Therefore TA×FH=AF×TE. And QB : BF : : QN : FD. Therefore QB×FD=BF×QN. But, as there is supposed to be equilibrium, AF×TE (the effective part of the power)=BF×QN (the effective part of the weight). Hence TA×FH=QB×FD. And TA : QB : : FD : FH.

the arms themselves are "perpendiculars" to their directions.

177. COMBINATIONS OF LEVERS.—With a system of levers like that represented, fig. 35, there is equilibrium, when "the power multiplied by the product of the alternate arms—beginning with that which is next the power, is equal to the weight multiplied by the product of the remaining arms." For, the velocity of the power, compared with that of the weight, is increased in the same proportion as the product of the alternate arms, beginning with that

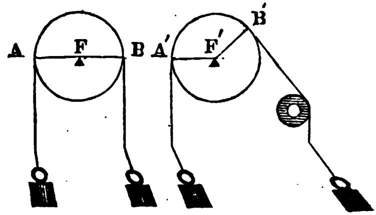
FIG. 35.



next the power, is rendered greater than the product of the remaining arms. Thus, the resistance, belonging to the lever at the right hand side (which is the power of the next lever), $=2P$; since the arm which carries the power is twice as long as the other. The resistance, belonging to the next lever (which is the power of the remaining one) $=$ $3P$, since the arms are as $3:2$. The resistance belonging to the remaining lever, is equal to three times its power; since one of its arms is three times as long as the other. That is, $W \times 1 \times 2 \times 1 = P \times 2 \times 3 \times 3$; or $W = 9P$.

178. THE PULLEY is a circular disc, turning on its centre, and carrying a cord, or chain, in a groove on its circumference. The case in which the disc turns is often called a *block*, and the disc or pulley itself a *sheaf*. A single block may contain many sheaves. In our calculations, we shall consider each disc as a pulley; since its effect is not altered, by its being in a separate block or not.

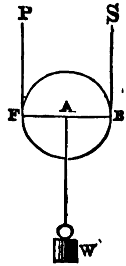
FIG. 36.



179. The *pulley* is a *modification of* the lever —*being a system of* le-

vers, of which only one of them AFB, or A′F′B′, fig. 36, or FAB, fig. 37, acts at a time; and all of them have a common fulcrum. Its action, therefore, is the same as that of the rectilinear, or the angular lever: but it has this advantage over it, that the power, and weight, are always perpendicular to the arms which carry them. The levers come, successively into action, without any interruption.

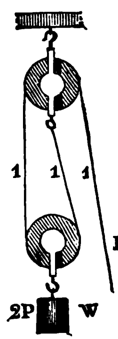
FIG. 37.



180. A pulley is either *fixed*, as in fig. 36, or *movable*, as in fig. 37. A fixed pulley, fig. 36, does not increase either the mass or the velocity of the weight; but it is often very useful, in changing the direction of the force. A movable pulley, FB, fig. 37, having one extremity of the cord fixed at P, and the power acting at S, may be considered as a lever of the second order, having the fulcrum at F, the weight at A, and the power at B.

181. COMBINATIONS OF PULLEYS.—A system of pulleys may be divided into that which has but one cord, and that which has more than one. When the latter is used, the extremities of the cords may be attached to a fixed support; or to the weight. When a system of pulleys, fig. 38, has but one cord, n being the number of movable pulleys, $W = P \times 2n$. For the sum of the weight and power is supported, by the sum of all the parts of the cord: but, since there is only one cord, all the parts must have the same tension:—or, in other words, each part must support the same amount of the sum of the power and weight. In this case, the cord is divided into three parts, therefore, each part sustains $\frac{P+W}{3}$; and, as two of them sustain the weight; and the remaining one the power—

FIG. 38.



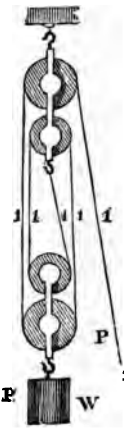
$$W = 2 \times \frac{P+W}{3} \text{ and } P = \frac{P+W}{3}$$

Therefore, $P : W :: \frac{P+W}{3} : 2 \times \frac{P+W}{3} :: 1 : 2.$ That is,

eight is equal to the power, multiplied by $2n$. The reasoning would hold with any number of movable ys.

2. Fig. 39 represents a combination of ys in which the sheaves of each block ot all on the same axis. But the mode lculating the effect is still the same. since there are but two pulleys in the : block, that is, two movable pulleys, 4P.

FIG. 39.



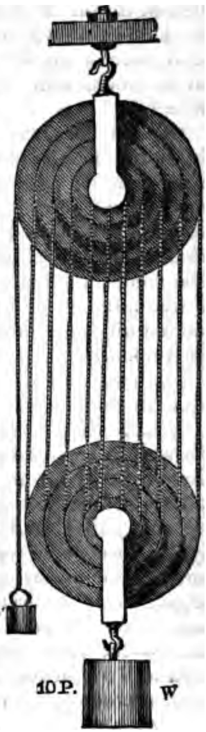
3. When there are several sheaves in ame block, there is a great loss of power friction. For the sheaves revolve with ıal velocities: each having to carry, in ion to the cord which runs from itself, at has run off from the preceding ones. wear and tear, also, is very unequal. examine the quantity of cord that is ed off, by each pulley, we shall find that elocities of the movable pulleys are as 5, &c., and of the fixed as 2, 4, 6, &c.— ith reference to themselves only, as 1, &c. If the sheaves are all of the same diameter; and reight is raised through a space, equal to the semi-mference of one of them; a portion, equal in length at semi-circumference, will have rolled off the first ble pulley, and twice as much off the first fixed pul- In the same way, if there are several pairs, since all ıovable pulleys are supposed to be raised to the same t, the semi-circumference of a sheaf will roll off from movable, and twice that quantity from each fixed y—the individual action of each pair, consisting of a and a movable pulley, being alone considered. But, there is more than one pair, each, besides its own on, must carry away also all the cord given off by the ys, the actions of which have preceded its own.

4. Hence, it is evident, that, when the diameters of ıovable pulleys are as 1, 3, 5, &c., they will all revolve e same time; and may, therefore, be formed of but iece. *Also, when the diameters of the fixed pulleys 2, 4, 6, &c., they will revolve in the same time with*

each other, and with the movable pulleys: or, if they are as 1, 2, 3, &c., they will revolve in the same time with each other:—and, in either case, they may be made of the same piece.

185. *White's Pulley*, fig. 40, intended to diminish the friction, wear, and tear, &c., is founded on these considerations. It consists of two blocks—a fixed and movable; the former contains a compound sheaf, the pulleys of which are as 2, 4, 6, &c., or 1, 2, 3, &c., and the latter a compound sheaf, whose pulleys are as 1, 3, 5, &c. This pulley is an example of excellence in theory being, by no means, necessarily accompanied by excellence in practice: its construction, and use, involve difficulties which allow it rarely, if ever, to be actually applied:—it is scarcely possible to prevent the cord from slipping in the grooves, and other inconveniences, almost invariably attend its use.

FIG. 40.

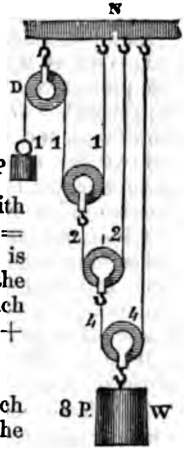


186. In calculating the effect to be derived from pulleys, we must take into account the relative directions of the power, and resistance. And the weight will always be found equal to "the power multiplied by twice the cosine of the angle, formed by either cord with the direction in which the resistance acts, and divided by the radius."*

187. When each movable pulley hangs by a separate cord, and the extremities of the cords are attached to a fixed support N, fig. 42, D being a fixed

* For, let the pulley H, fig. 41, from which the weight W is suspended, be sustained by the cord EHD. The portion of W supported by EH is equal to the portion sustained by HD [181]. And

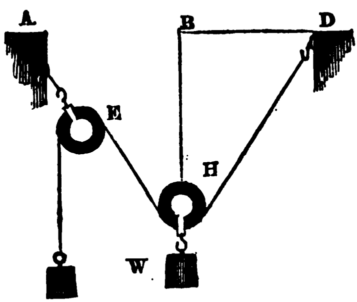
FIG. 42.



, intended to alter the direction
power, if n is the number of
ole pulleys, $W = P \times 2^n$. To be
iced of this, we have only to ex-
, what multiple of P is sustained,
ch part, of every cord; and what
er of cords, actually, support W.
e present example, of the four
which sustain the weight, the
ire on each of the two, connected with
wer=P; the pressure on the next=
and that, on the last,=4P. This is
ted by the numbers, attached to the
nt cords. Hence the cords, which
rt the weight, sustain $P + P + 2P +$
$1 + 1 + 2 + 4) \times P = 8P$.
And $W = 8P = P \times 2^3 = P \times 2^n$.
is to be borne in mind, that each
added, to this system, *doubles* the

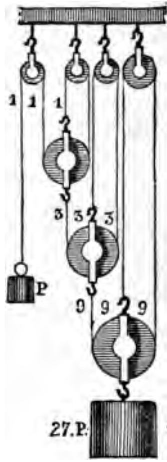
ight is equal to the sum of their effective parts—or,
he tensions are equal, to twice the effective part of one.

FIG. 41.



), one of them, be
l into HB, effi-
because opposed
vity) and BD,
inefficient. The
may be repre-
by 2 HB; while
ces, expended in
ng it, may be re-
ed by 2 HD:—
e part of them,
elong to the power
. Hence P:W::
B. But if HD is
HB will be cosine
ngle DHB, made
of the cords HD, with BH, the direction in which the
ce acts. Calling this angle a, $P : W :: R : 2 \cos. a$. And
$\frac{2 \cos. a}{R}$.

FIG. 43.



188. Fig. 43 represents a similar system, in which the same number of movable pulleys is used:—but, in this case, $W = P \times 3^n$. The number of cords supporting the weight is increased; and we can ascertain the mechanical advantage, in this case, also, by examining what part of the weight, is sustained, by each portion of the rope; and adding together the results. We, thus, find that, with an arrangement containing three movable pulleys, $W = P \times 3^3 = P \times 3^n$.

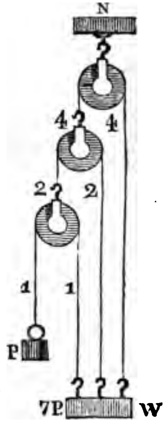
It is easy to see, that each cord, added to this system, *triples* the effect.

189. If the extremities of the cords are fastened to the weight itself—the whole being suspended from a single point of support N, fig. 44, we are to subtract the amount of the power, from that of the weight—as determined in the former instance [187]. Hence $W = P \times (2_n - 1)$. For, estimating, as before, the pressure sustained by each cord; and adding the results; we find that, of the three cords which now sustain the weight, the pressure on the one to which P is attached $= P$; that the pressure on the next cord $= 2P$; and that the pressure on the last $= 4P$. Therefore the cords, which support the weight, sustain $P + 2P + 4P = (1 + 2 + 4) \times P = 7P$.

And $W = 7P = 8P - P = P \times (2^n - 1)$.

The mechanical effect is diminished, because the weight is sustained by one cord less than in the former system—the *tension* of that cord being $= P$.

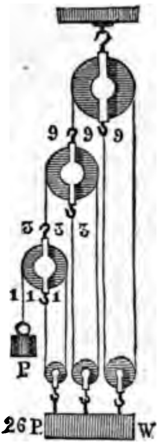
FIG. 44.



In this system, each additional cord more than doubles *the effect.* *It is* merely fig. 42 reversed.

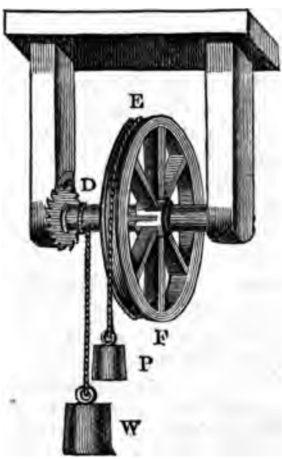
It may be modified, as already
:d [188], so as to assume the
presented, fig. 45; and we are
act the power from the amount
veight, as then obtained. For,
ng the pressure sustained by the
t cords, and adding the results,
›ver that, with three movable pul-
$=26P=27P-P=P\times(3^n-1)$.
mechanical effect is diminished,
ame way, and for the same rea-
with the system, fig. 44.
ıis system, each cord more than
the effect. It is merely fig. 43
l.

FIG. 45.



stem of pulleys, having but a
ord although less powerful than
sponding system having, two,
ɛc., is much more con-
for ordinary purposes.
there is more than one
he pulleys soon come
ıtact; and their effect
ases. Besides, a sys-
h several cords is more
to be fixed, applied,
naged.

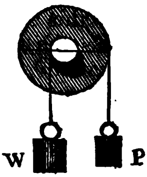
A FIG. 46. B



THE WHEEL AND
s a modification of the
ith unequal arms. It
of two parts: the
-or something tanta-
o it—which causes the
ɔo describe a large cir-
ıd the axle—which
;he weight to describe
ɜr one. The cord, con-
with the power, is ap-
the rim of the wheel
!6; *and that* which is attached to the weight, to
D. A ratchet wheel, which we shall describe pre-

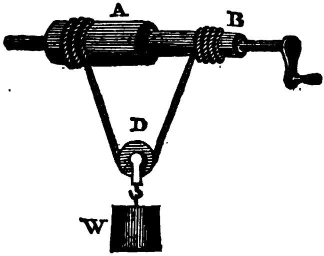
sently, prevents the weight from running down—if the action of the power is, from any cause interrupted. The wheel and axle, like the pulley [179], is resolvable into a system of levers, having a common fulcrum—the centre of the axle, fig. 47—and coming into action successively, only one of them being, at any time, in operation, and its arms not being in the same plane. The radius of the axle is the shorter, and the radius of the wheel, the longer arm; the weight being attached to the former; and the power to the latter. Hence, from the properties of the lever [158], when there is equilibrium, P × the arm to which it is attached = W × the arm to which it is attached. That is, "the power multiplied by the radius of the wheel, is equal to the weight multiplied by the radius of the axle." The mechanical advantage being due to the difference between the radius of the wheel, and that of the axle, the greater this difference the greater the effect. When, therefore, we desire to increase the efficiency of the wheel and axle, we must increase this difference, by making the wheel larger, or the axle smaller; or by doing both together. But there must necessarily be a limit to such increase or diminution: otherwise the wheel will become too large, or the axle will be made so small as to be no longer capable of supporting the weight. This inconvenience is removed by the following contrivance—

FIG. 47.



192. THE DIFFERENTIAL AXLE is constructed on the great mechanical principle [152], that the effect of any machine depends on the excess of the velocity of the power over that of the weight. It consists of an axle, having its two portions A and B, fig. 48, of different diameters. *B, the smaller*, lets down *the rope, and*, consequently, the weight, while A, the *larger, coils it up*, and, therefore, raises the weight. If

FIG. 48



the two parts of the axle were of the same diameter, the rope would be coiled up, and let down to an equal extent; in which case, the weight would move, neither up, nor down. The smaller the difference between the diameters of A and B, the less the weight will be raised with a given motion of the power; and the greater, therefore, must be its mass—that is momentum may be equal to that of the power. And, since we can make the two diameters as nearly equal as we please, there is no limit to the effect of such a machine, but the strength of the materials of which it is formed—and the more powerful, the stronger it is. The differential axle has been long used by the Chinese.

193. We may use a winch, handspikes, &c., in place of the wheel, but the principle is the same; for the power in all these cases, describes a circle, which occupies the place of the circumference of the wheel.

194. EXAMPLES OF THE WHEEL AND AXLE.—The *capstan* used in ships, is a species of wheel and axle. It consists of a vertical beam, which, being made to revolve by handspikes, or *capstan bars* inserted into its upper portion, draws the rope or chain with great force.

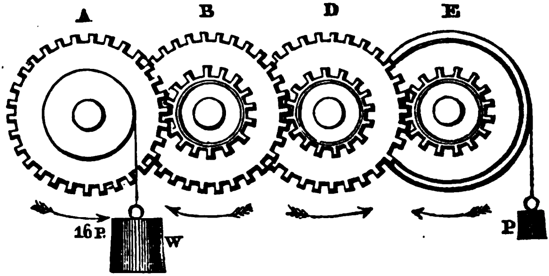
The *windlass* resembles the capstan in form, except that the portion on which the rope or chain is coiled, is horizontal; and the handspikes move in a vertical plane.

The capstan is more convenient than the windlass, since its effect is produced *continuously:* but the force is derived from muscular strength, and not, as with the windlass, from the weight of the body—which is a disadvantage. Working at a capstan, a man can exert a force of only about thirty-five pounds, while with a windlass his whole weight is effective.

The *crane*, also, is a kind of wheel and axle, &c.

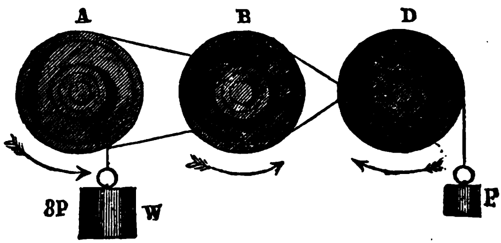
195. COMBINATIONS OF WHEELS AND AXLES.—A number of wheels and axles may be made to act together: but then they require to be modified: the axle becomes, what is called, the *pinion*—a small wheel, working into the large one, belonging to the next wheel and axle. Wheels are sometimes made to drive each other by teeth, as in fig. 49. The teeth of the pinions are called leaves. *Such a system enables us to increase, either the mass, or the velocity of the resistance.*

FIG. 49.



196. Sometimes, wheels are made to act together by bands, as in fig. 50. This is a very convenient arrange-

FIG. 50.



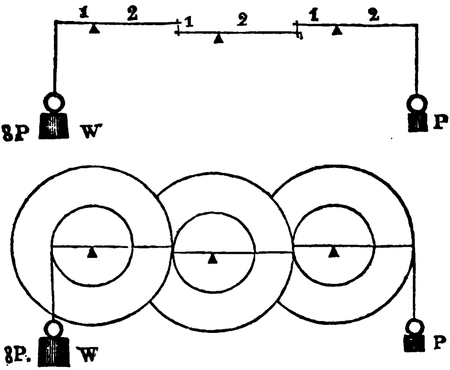
ment; since, by means of it, they may be used to drive one another, although separated by a considerable space; and the motion may be either *direct*, as that which is imparted by B to A: or *reverse*, as that which is imparted by D to B.

197. Sometimes, wheels are made to work together, by mere friction; which gives an extremely smooth, and noiseless motion, and is very convenient, where the resistance is not great—as in certain portions of the machinery of cotton mills, &c.

198. With a system of wheels and pinions, "the power multiplied by the product of the numbers of teeth in the wheels, is equal to the weight multiplied by the product of the numbers of leaves in the pinions." The radii of the wheels, are the longer arms, and the radii of the pinions, the shorter arms of such a system of levers as we have

y ex-
d[177].
is evi-
rom fig.
hich re-
tsa sys-
'wheels
xles a-
vith the
ponding
n of le-
– these
, only to
the mu-
ction of
wheels

FIG. 51.



xles is referable, being represented. Hence, a sys-
' wheels and axles being identical in principle with
em of levers, the power of each is calculated in a
r way. And [177] the equation for the system of
and for the corresponding system of wheels and
fig. 51, will be

$$W \times 1 \times 1 \times 1 = P \times 2 \times 2 \times 2; \text{ or, } W = 8P.$$

, since the circumferences of the wheels and pinions
oportional to their radii, we may substitute these
iferences for the corresponding radii: and the equa-
ien becomes, "the power multiplied by the product
circumferences of the wheels, is equal to the weight
lied by the product of the circumferences of the
s." This enables us to estimate the effect, when the
s act on each other, either by bands or friction.
as the numbers of teeth, or leaves are, respectively,
tional to the circumferences of the wheels and
s, when teeth are used, we may substitute, for the
iferences of the wheels and pinions, the numbers of
hey, respectively, contain.

AMPLE 1.—There are three wheels A, B, and C;
ree pinions, D, E, and F. A has 97, B 43, and C
th; D has 12 leaves, E 15, and F 17. How many
s attached to the wheels, will retain, in equilibrio,
s. attached to the pinions?

$$P \times 97 \times 43 \times 84 = W \times 12 \times 15 \times 17$$
$$\text{That is, } P \times 350364 = W \times 3060$$
$$\text{And } P \times 350364 = 1321920 \text{ lbs.}$$
$$\text{Hence, } P = \frac{1321920}{350364} = 3{\cdot}773 \text{ lbs. nearly.}$$

EXAMPLE 2.—In a system of wheels and pinions, driven by bands, there are four wheels, the circumferences of which are, respectively, 34, 27, 56, and 62; and four pinions, the circumferences of which are, 11, 13, 14, and 17. What is the ratio of the weight to the power?

$$P \times 34 \times 27 \times 56 \times 62 = W \times 11 \times 13 \times 14 \times 17$$
$$\text{That is, } P \times 3187296 = W \times 34034.$$
$$\text{Hence, } W : P :: 3187296 : 34034 : 93{\cdot}65 : 1, \text{ nearly.}$$

EXAMPLE 3.—A system must consist of three large, and three small wheels, acting by bands. The circumferences of the latter are as 8, 10, and 12; and of two of the former as 45, and 55:—what must be the circumference of the third wheel, so that the weight may be 127 times the power? Let x be the circumference of the required wheel. Then

$$P \times 45 \times 55 \times x = P \times 127 \times 8 \times 10 \times 12$$
$$\text{And } 2475x = 121920. \text{ Therefore}$$
$$x = \frac{121920}{2475} = 49{\cdot}26, \text{ nearly.}$$

In figs. 49, 50, and 51 the diameters of the wheels are supposed to be twice those of the pinions:—therefore, in fig. 49, W=16P: and in figs. 50 and 51, W=8P.

FIG. 52.

A

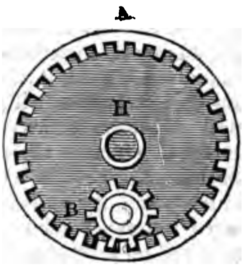
B

199. DIFFERENT KINDS OF WHEELS.—Wheels are divided into crown, spur, and bevelled gear. The *crown wheel* is so called, on account of its resemblance to a crown, having its teeth perpendicular to its plane.

200. The *spur wheel* has its teeth, which are continuations of radii, fixed on its rim. When the wheel is of large size, the rim is connected with *a boss, in the centre,* by arms—as in *B, fig. 52. When it is* smaller, the

rim and boss are united by a thinner portion: and it is, then, said to be a *plate* wheel. When still smaller, the entire wheel is of uniform thickness. The axis upon which a wheel revolves, is termed a *shaft* or *spindle*. If the power, to be transmitted by the wheel, is considerable, the latter is fastened to the shaft, by one or more wedges, called *keys*, which are forced into grooves cut transversely, in the boss through which the shaft passes, and which generally rest upon flat faces, formed on those parts of the shaft immediately under them.

FIG. 53.



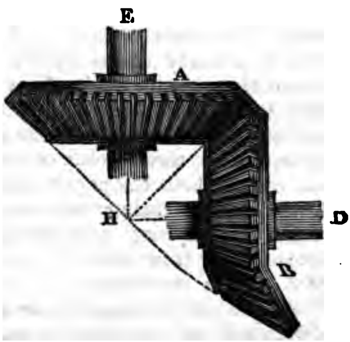
201. The *annular wheel* has the pinion B, fig. 53, within it. The friction is less when the pinion is inside, than when it is outside the wheel.

202. When one wheel drives another, the former is called the *driver*, and the latter the *follower*. If a wheel is used merely to transmit motion, between two other wheels, it is called a *carrier:* and alters the direction of motion, but not the velocity.

When a wheel A, fig. 52, drives a pinion B, the latter should have, at least, eight leaves. But when the pinion drives the wheel, the former should have, at least, six leaves.

Sometimes a *rack*, which is a straight bar having teeth on one of its sides, is driven by a pinion: and, sometimes, a pinion by a rack.

FIG. 54.



203. *Bevelled wheels.* — The wheels which work together, are not always in the same plane. In such a case those which have oblique teeth, and are termed "bevelled wheels," are generally *employed. They* are the *frusta of cones*, channelled *from their* apices to

their bases. The mode in which they are constructed, and the kind of action they exert upon each other, may be understood from A and B, fig. 54. The axles E and D, may form any angle which the circumstances require.

204. When bevelled wheels, having different diameters, are to work together, the sections of these cones, of which they may be considered portions, are found as follows. Let AB, fig. 55, be the greatest diameter of the large wheel, and BD that of the smaller. Bisect AB, in X: and BD, in Z. At X and Z, erect perpendiculars intersecting each other at E. Join E with A, B, and D: the resulting triangles will, if they revolve, respectively, on XE and ZE, form cones: and ASPB, BPHD may be supposed to generate the required bevelled wheels. The sum of the angles made by EB will be 90°: all corresponding points of the two cones will have the same relative velocity, and they will roll on each other.

FIG. 55.

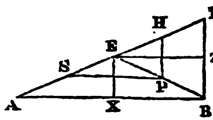
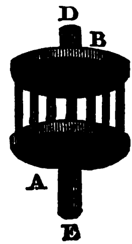


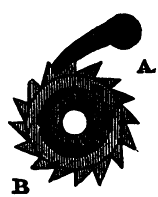
FIG. 56.



205. Sometimes, in the rude machinery of country mills, &c., the *trundle* or lantern, supplies the place of a pinion. It consists of an axis, DE, fig. 56, and two circular discs A and B, connected by rods or spindles, which are placed near the circumferences of the discs.

206. The *ratchet wheel*, fig. 57, to which we have already alluded [191] is used to prevent the rope, or chain, from being uncoiled by the action of the weight or resistance, should any cause relax or destroy the power. It can turn in only one direction—that, which allows the power to act: motion in the opposite being prevented, by the ratchet A dropping into the notches, in succession, as B revolves.

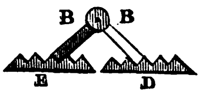
FIG. 57.



207. When the ratchet is attached to a capstan, the notches are inclined equally, at each side; and the ratchet *may be made* to act both ways, by causing it to abut

against the notches, as represented by BE, or B′D, fig. 58: we may thus prevent, or allow motion in either direction, at pleasure. The ratchet is attached to the capstan, and travels round along with it; the notches, into which it drops, are fixed to the deck in a circle round its base.

FIG. 58.



208. TEETH OF WHEELS.—It is very important that teeth and leaves, working together, should roll, and not drop nor slide on each other—either of which latter would cause wear, and loss of power.

When teeth *fall* on each other—being unconnected with the resistance, during the drop—they acquire an increased velocity, and therefore, a momentum, which is injurious to the machinery, and is productive of no useful effect, since the motion is too sudden, and of too short duration [6], to be communicated to the rest of the train: consequently it cannot increase the work done. This dropping of the teeth always causes noise:—hence we may form some idea of the goodness of mill-work, &c., by the comparative silence with which it acts.

The defects of wheels are, generally, due to the incorrect form of the teeth:—the accurate construction of the latter, therefore, becomes a matter of great importance.

209. The *pitch* of the wheel, is the width of a tooth and a space, measured on the *pitch circles*, which are the working circumferences of the two wheels acting together—or those circles of each, which may be considered to come into contact, during their revolution. It is found, however, more convenient in practice, to consider the pitch as depending on the number of teeth and spaces, corresponding to an inch on the diameter of the pitch circle. Thus, if there are 16 teeth to an inch of this diameter, the pitch is said to be $\frac{1}{16}$.

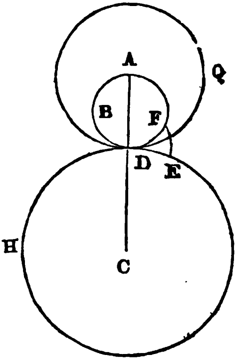
The line of centres, is a line passing through the centres of the pitch circles, and the point of contact. The part of the tooth outside the pitch circle is called the *face*, and that which is inside of it the *flank* of the tooth.

The face of the tooth is an epicycloid, &c.: its flank is a radial line.

The curves, which answer best for teeth, are the epicycloid* and involute.†

210. To describe *epicycloidal teeth.* The diameter of the *generating circle* of one wheel, should be equal to half the diameter of the pitch circle of the other. Let HO, fig. 59, be the pitch circle belonging to one of the wheels which are to work together—and the teeth of which are to be described: let EQ be the pitch circle of the other: and let AC be the line of centres. If the generating circle BF is made to roll on the pitch circle HO, F, some point of it, will describe the epicycloidal curve FE. This will be the face of the required tooth. The flank may be described with a radius.

FIG. 59.

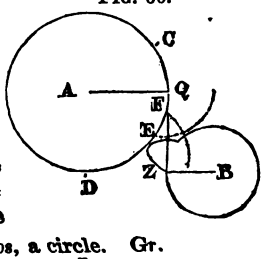


Epicycloidal teeth act perpendicularly to the line of centres, at the instant of crossing it.

Two wheels with epicycloidal teeth will not work well together, unless they are equal. To obviate this inconvenience, the same generating circle is sometimes used for both wheels.

211. To describe teeth, which are the *involute of a circle.* Let A and B, fig. 60, be the centres of the pitch circles, belonging to the wheel and pinion, on which the teeth and leaves are to be formed. Take EF equal to the base of the intended tooth, and fix, at any point, C—to be determined by the height of the tooth—one end of a cord or thread. Let this cord lie along the circumference, and reach to E. Its extremity E will, if rolled off, describe a curve: this will be the face of the tooth. Take FD=*EC; fix one end* of the same

FIG. 60.



* *Epi,* upon: and *kuklos,* a circle. Gr.
† *Involvo,* I roll upon. *Lat.*

cord at D, and let its other extremity F describe a curve, intersecting the former. The space between the circle, and the intersection of the curves will be the tooth. The flank may be described by a radius. This tooth, marked on the other pitch circle, will be the leaf of the pinion.

212. Involute teeth do not slide, nor drop, but roll on each other; and since a line QZ, passing through the point of contact, will always be tangential to the circumference of the wheel and pinion, their mutual action will [111] be most favourable to the communication of motion, from one to the other. A difference between the lengths of their radii does not injure the mutual action of wheels having involute teeth:—so that any two wheels of the same pitch will work well together.

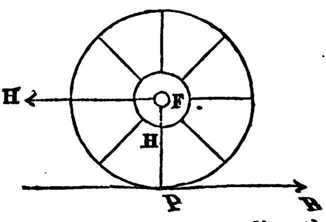
Involute teeth have an oblique action, and throw a greater divergent strain on the axis of wheels than other teeth.

213. A pinion with involute teeth will work a rack, having teeth that are straight sided, and inclined to their pitch line. Involute teeth, strain a rack very little by lateral pressure.

214. If the number of teeth in a wheel, is an exact multiple of the number of leaves, in the corresponding pinion, the same leaf will always come into contact with the same teeth: and the injurious effect of any inaccuracy of workmanship, will be greatly increased. To prevent this inconvenience, a tooth called the "hunting cog" is added to the wheel.

Wooden and metallic teeth work together, with little, or no noise.

Fig. 61.

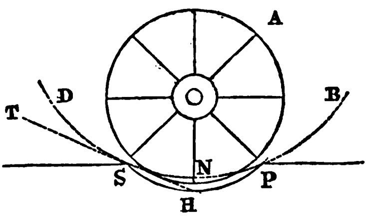


215. *Wheels of Carriages.*—The difficulty of drawing a load, arises from the friction between the axle and the box of the wheel. PF, fig. 61, may be considered as the lever in action: F being the fulcrum, H the resistance—*at the point* where the axle *and box are forcibly* rubbed together, and PB the direction

of the power. As far as momentum is concerned, it is evidently the same, whether the axle is drawn along FH, or the point P is moved in the direction PB; for the friction of the axle and box is in both cases, overcome by a force acting at P. The longer the radius of the wheel, the longer the arm at which the power acts. If, however, the radius is too great, the spoke will be too heavy, or too weak. Besides, the horse will draw at a disadvantage, since [137] his force should be applied nearly, in the direction of a horizontal line, passing through the axle. The trace, however, as Deparcieux has shown, must not be exactly horizontal, when the horse is at rest: but should slightly descend towards the road: since he pulls by his weight, and by lowering his chest—his hind feet being used as a fulcrum. We shall find, also, that a portion of the power is usefully employed to diminish the effect of gravity, in producing a friction. It is evident, that the smaller the radius of the axle the better, provided it is sufficiently strong.

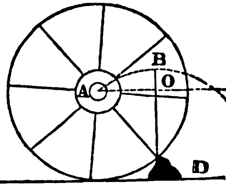
216. High wheels are drawn over obstacles, more easily, than those which are low: whether these obstacles arise from hollows or prominences. For, a large wheel will sink either but little, or scarcely at all, into a rut SHP, fig. 62—which is equivalent to an inclined plane HT. For, the large wheel—a portion of which is represented by the dotted line DNB—will, evidently, be less affected by the rut, than the smaller one A.

FIG. 62.



217. The sinking of an inelastic road—one of sand, for example, or of clay—produces an uncounteracted pressure, in front of the wheel. Any road, that yields under the weight of the carriage, gives rise to an effect which is equivalent to a continued ascent. Roads over bogs, however good in appearance, will, if carefully watched, be perceived to sink beneath the wheel; and to rise again when the pressure is removed.

FIG. 63.



218. If an obstacle, such as a stone, D, fig. 63, is to be overcome, a large wheel is better, for the purpose, than a small one. The centre of gravity of that part of the load, the weight of which is borne by the wheel, may be supposed to be at the axle, and it must, while describing a curve ABH, rise to B, through the distance OB—which is equal to the height of the obstacle. The larger the curve—which acts as an inclined plane—the easier it will be to lift the weight at A, through the distance OB: as will be seen, when we come to the properties of the inclined plane. But, as the length of the curve is proportional to the radius which describes it, the longer the radius the better:—that is, the larger the wheel, the more easily it passes over stones, &c.

219. The fall of the wheel off an obstacle, injures the road:—hence, wherever the latter is crossed by an elevated pavement, a row of stones, or any substance higher or harder than the general surface, a hollow is soon formed at each side of the pavement, &c. The same cause makes the ruts of a neglected road to deepen rapidly.

220. Low fore wheels cause a carriage to be more easily turned; but, ordinarily speaking, they have no other advantage. They increase the friction; since, to pass over a given space, they require to revolve more frequently than those which are larger.

221. When *dished* wheels descend into a rut, the spokes assume the position, best adapted for supporting the strain, which is thrown upon them—since they are then perpendicular, or nearly so; but their advantages seem, on the whole, to be, at least counterbalanced, by their disadvantages.

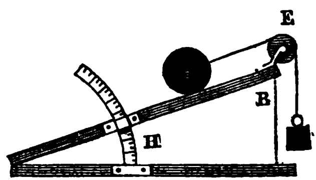
222. A carriage with springs is more easily drawn, than one which has none; because—on account of its inertia [6]—it has not time to sink, or rise, at every trifling inequality that presents itself to the wheels. This is particularly true if the motion is rapid.

223. When springs connect the axles and wheels with the rest of the vehicle, not only the carriage itself, but th

horses, also, are saved from the shocks, produced by the ruggedness of the road.

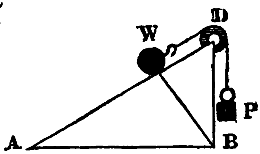
224. THE INCLINED PLANE is a smooth plane AB, fig. 64, making with the horizon some angle BAP, called "the angle of inclination." BP, the sine of this angle, is the *height* of the plane; AP, its cosine, is the *base;* and AB, the radius, is the *length* of the plane.

FIG. 64.



225. If a body is kept in equilibrio on an inclined plane, the power may act in a direction parallel to the length; or to the base; or, in general terms, it may make any angle with a perpendicular to the length. Calling the length L, the height H, and the base B, if the power acts in a direction parallel to the length, P : W : : H : L. For, a body W, fig. 65, is kept at rest on the inclined plane, by three forces [108]; the power, represented by WD : gravity, by DB : and the reaction of the plane, by BW. Therefore P : W : : WD : DB. But, since the triangles BDW and ADB are similar, WD : DB : : DB : AD, that is, : : H : L.

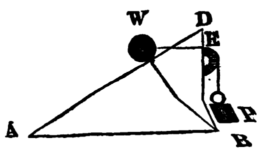
FIG. 65.



226. When a horse draws a load, upon an inclined plane, to a certain extent he lifts the load. Thus, if the rise is one in thirty, he lifts the thirtieth part of it. For, gravity is to its effective part : : DB : WD : : AD : DB : : L : H. Therefore, the effective part of gravity is equal to $\frac{H}{L}\times$ the force of gravity.

227. If the power acts parallel to the base, P : W : : H : B. For the body W, fig. 66, is kept at rest by three forces: the power, represented by WE: *gravity, by EB;* and the reaction of the plane, by BW. *Hence, P : W : :* WE : EB. But,

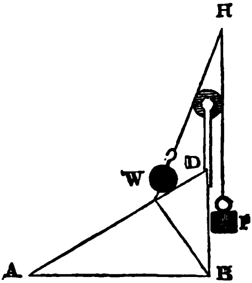
FIG. 66.



since the triangles BWE and ADB are similar, WE : EB : : DB : AB—that is, : : H : B.

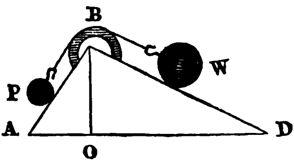
228. Whatever may be the direction of the power, P : W : : sine of the angle of the plane's inclination : sine of the angle, made by the direction of the power with a perpendicular to the plane. For, the body W, fig. 67, is kept at rest by three forces : the power, represented by WH ; gravity, by HB ; and the reaction of the plane, by BW. Therefore, P : W : : WH : HB. But, the sines of angles being proportional to the sides opposite to them, WH : HB : : sine WBH : sine HWB. Therefore, since DAB (the angle of inclination)=WBH, and HWB is the angle, made by the direction of the power with WB, a perpendicular to the length of the plane, P : W : : sine of the angle of inclination : sine of the angle, made by the direction of the power with a perpendicular to the plane.

Fig. 67.



229. When two bodies P and W, fig. 68, support each other, on inclined planes which have a common height BO, "one of them is to the other, as the lengths of the planes on which they rest:"—because the longer the planes, the greater the amount to which the bodies are supported ; and the less, therefore, the action which they exert :—hence, the greater they must be, to produce a given effect. Also, as P and W balance each other, the efficient part of the force, derived from each, must be the same. Let us call this *f* ; and in the first instance, let us suppose W to be the weight. Since the direction of the power is parallel to the length of the plane [225], *f* : W : : BO : BD. Next, let P be the weight :—for the same reasons, *f* : P : : BO : BA. Alternating these two proportions we have

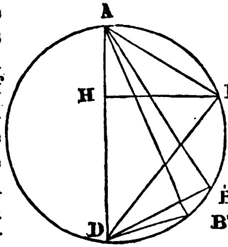
Fig. 68.



f : BO : : W : BD, and
f : BO : : P : BA.
Hence W : BD : : P : BA, and alternating,
W : P : : BD : BA.

230. Descent of Bodies, down Planes, and Curves.—"A body, will, under the influence of gravity, fall through a vertical diameter AD, fig. 69, and any chord AB, or BD, joining either of its extremities, in the same time." If the body is kept on the chord, by means of an inclined plane AB, it is acted upon by two forces: the reaction of the plane, represented by DB; and gravity, by AD; and it will describe the resultant AB, in the same time [107] as any side of the rectilineal figure, representing the forces which produce it, would be described by the force corresponding to that side. Hence AD and AB would be described in the same time. In the same way B′D, the resultant of B′A and AD would be described in the same time as AD. Also B″D, the resultant of B″A and AD, in the same time as AD.

Fig. 69.



If the chords DB, DB′, &c., are inclined planes, when AD represents the whole effect of gravity, acting on a body descending along them, each of them will represent its efficient part, or the accelerating force—which, therefore, will vary, as their lengths, respectively: that is, as the space to be described under its influence.

231. This enables us to find, in what time a body would descend, through any inclined plane:—since, if the given plane is AB, fig. 69, we have only to produce the line AH, representing its height; and, from B, to draw a line perpendicular to AB, and intersecting AH produced, at any point D. The body will descend along the plane, in the same time as [230] it would, under the influence of gravity, have fallen from A to the point of intersection D. For, if we draw a circle through the three points A, B, and D, AD will be a diameter; and AB, a chord joining one of its extremities.

232. If the arcs D′B, and DB″ *are very small, they may*

be considered as coincident with their chords; and a body may be supposed to descend through them, also, in equal times.

The same thing is true, if the body is retained in these arcs, by a string, &c.

233. The time, during which a body would fall down an inclined plane, is equal to "the square root of the quantity, obtained, by dividing twice the length by $32\frac{1}{6}$, and then multiplying the result by the quotient of the length divided by the height."*

EXAMPLE.—In what time will a body fall down an inclined plane, the length of which is 20, and its height 10 feet?

$$\sqrt{\left(\frac{40}{32\frac{1}{6}}\times\frac{20}{10}\right)}=\sqrt{\left(\frac{40}{36\frac{1}{6}}\times 2\right)}=\sqrt{\frac{80}{32\frac{1}{6}}}=$$
$$\sqrt{(2{\cdot}4870)}=1{\cdot}577''.$$

234. The velocity acquired by a body in falling down an inclined plane, is equal to what is acquired by falling through its height. That is, "it is equal to the square root of the product, obtained by multiplying together twice the length, the quotient of the height divided by the length, and $32\frac{1}{6}$."†

* For the time of descent is the same as that, during which the body would fall through the diameter AD, fig. 69.

That is, [60], T being the time, $T=\sqrt{\frac{2AD}{32\frac{1}{6}}}$.

But, since AD:AB::AB:AH, $AD=AB\times\frac{AB}{AH}$.

Or, calling AB,L; and AH,H; $AD=L\times\frac{L}{H}$

And, substituting this value of AD, in the equation $T=\sqrt{\frac{2AD}{32\frac{1}{6}}}$, we get $T=\sqrt{\left(\frac{2L}{32\frac{1}{6}}\times\frac{L}{H}\right)}$

Since $T=\sqrt{\frac{2AD}{32\frac{1}{6}}}=\sqrt{\frac{4\text{ radius}}{\text{force of gravity}}}=2\times\sqrt{\frac{\text{rad.}}{\text{f. of grav.}}}$, when the force of gravity is constant, T varies as the square root of the radius.

† For, V being the velocity, V = the square root of the product obtained by multiplying together the force of gravity, and twice the space [58]. But [226] the effective part of gravity is, in this case, represented by $\frac{H}{L}\times 32\frac{1}{6}$: and the space = L. Therefore $V=\sqrt{(2\times L\times\frac{H}{L}\times 32\frac{1}{6})}$.

EXAMPLE.—Let the plane, as in the last case, be 20 feet long, and 10 feet high. The velocity of the body, after falling down through it, will be

$\sqrt{\left(40\times\frac{10}{20}\times32\frac{1}{6}\right)}=\sqrt{(20\times32\frac{1}{6})}=25{\cdot}364$ feet, per second, nearly.

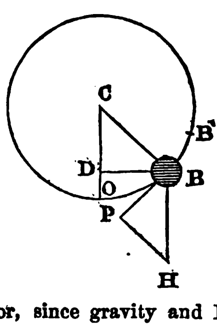
Hence, the velocity, acquired by falling down a plane of a given length, varies as the square root of its height. And, though the times of descent through different chords are equal, the velocities acquired in falling, are not so.

235. If the arcs are not *very* small, the times of descent through them will not be equal.*

236. But, if the body traverses a *Cycloid*, the curve described by every point of a carriage wheel as it rolls along a plane, it will descend through both large and small arcs in equal times.†

* For, the descent through the different chords DB, DB′, &c., fig. 69—which are also the sines of the angles DAB, DAB′, &c., belonging to the respective right-angled triangles—are made in equal times, because [230] these chords indicate that part of gravity, which produces motion, in the directions which they represent; and, in proportion as they are increased—that is, in proportion as the body has to traverse a longer space—the efficiency of gravity, the moving force, is also increased. When a body moves in the arc of a circle, the effective part does not vary as the arc to be described, but as the sine of the angle measured by that arc. For, the body B, fig. 70, if it describes the arc BO, must move in the tangent BP. But BH representing gravity, and PH being parallel to CB, BP will represent the effective part of gravity. Therefore, gravity : its effective part :: BH : PH. And, since the triangles BHP and BCD are similar, BH : BP :: BC : BD. Hence, gravity : its effective part :: BC : BD. And the effective part of gravity $=\frac{\text{gravity}\times\text{BD}}{\text{BC}}$.

FIG. 70.

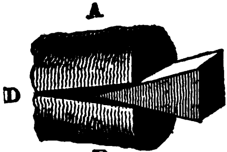


Consequently, it varies as $\frac{\text{gravity}\times\text{BD}}{\text{BC}}$ or, since gravity and BC (the radius) are constant, as BD. That is, as the sine of the arcs BO, B′O, &c.; but not as the arcs themselves, which are the spaces to be traversed.

† For, the efficient part of gravity will then be proportional to

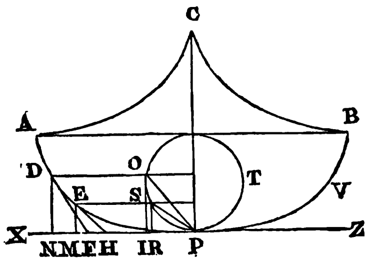
237. THE WEDGE, is used for splitting wood, &c. A very common form of this mechanical power, is represented, fig. 72. It consists of one or more *movable* inclined planes, which follow the same laws, as those which are fixed. If, instead of drawing the body up an inclined plane, the inclined plane is drawn under the body—so as to raise it, the inclined plane, will be changed into one species of wedge, the properties of which, may be easily inferred, from what we have already said [227].

FIG. 72.



the amount of the curve traversed. Let AB, fig. 71, be parallel to XZ. Let DN, EM, OI, and SR, be perpendicular to AB. If the circle T is rolled along AB, any point of it, P, will describe the cycloid BPA. DF, and EH are tangents to the curve, at the points D, and E; and, from the nature of the curve, are parallel to OP and SP—chords of the circle OTP; and the cycloidal arc DEP is double the chord OP; EP is double the chord SP, &c. Since DF is a tangent to the curve, at D, when the body is that point, it may be considered as moving along an inclined plane DF—or, as DFN and OPI are similar, along OP; and, for like reasons, when at E, along an inclined plane SP. But [230] the effective part of gravity is, in such a case, proportional to these planes:—that is, it varies as DF: consequently, as 2DF (=2OP); and, as the curve DEP (=DF). That is, the accelerating force varies as the space to be described, which, therefore, must always be described in the same time.

FIG. 71.



It is curious that a body will descend, by a cycloid, more quickly than by any other line, whether straight or curved; a fact which has been applied to practical purposes.

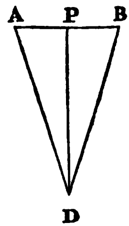
A body at P, suspended by a cord CP, will be made by means of cycloids CA, and CB—arranged so as to bend the chord—to describe the cycloid APB similar and equal to them. A body will vibrate in nearly equal times in very small arcs of a circle [232], also, because the curve at P, the vertex of the cycloid, is nearly coincident with a circle described with a radius CP—the latter being a common radius of curvature at P.

238. When there are two inclined planes having a common base, the back of the wedge is the sum of their heights; the action of the power is perpendicular to the back; and the effect of the wedge is [76] in directions perpendicular to the lengths of its planes.

239. There are two great sources of difficulty in calculating the effect of a wedge. First, the momentum imparted to it, is generally derived from a hammer, &c., the velocity of which cannot be easily estimated; secondly, its friction is enormous.

240. We shall consider only, the isosceles wedge, ADB, fig. 73—which is generated by the motion of an isosceles triangle, parallel to itself, along a right line perpendicular to its plane. With such a wedge, P:W::its back:twice its height; or::twice the sine of half the angle at the vertex: twice the cosine of the same angle. For, since the planes AD, and DB, are equal, the effect of both is double the effect of one. But, with AD alone, $\frac{P}{2}:\frac{W}{2}::$ AP : PD :: sine ADP : cos. ADP. And (multiplying all the terms by 2) P:W::2 × sine ADP:2 × cos. ADP.

FIG. 73.



241. THE SCREW is a combination of inclined planes, P, D, and E, fig. 74, wrapped round the cylinder AB. Any one of them has, for its *base*, the circumference of the cylinder; for its *height*, the distance between the threads; for its *length*, one revolution of the spiral: and all are equal. It may be considered as generated, either by wrapping one inclined plane PEH, several times, round the cylinder AB: in which case, there will be, practically, as many inclined planes, as distinct spirals. Or wrapping the inclined plane BDEP, fig. 75, once round the cylinder HO: so as to form but a single spiral.

FIG. 74.

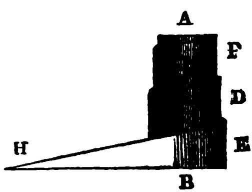
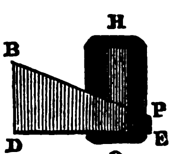
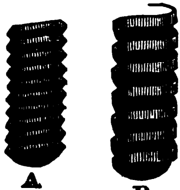


FIG. 75.



242. The threads of a screw are sometimes angular, as in A, fig. 76; and sometimes square, as in B:—each kind has its advantages, and disadvantages. When the threads are square, the *height* is a thread and space. The manner, in which the threads are formed, is a matter of considerable importance: since in many instances much depends on their accuracy. The distance between two threads, when they are angular, or a thread with a space, when the threads are square, are called the *pitch.* A screw is *right handed*, or *left handed*, according to the direction of the spirals. The *solid* screw A or B, fig. 76, works in what is called the *nut* or *hollow* screw.

FIG. 76.



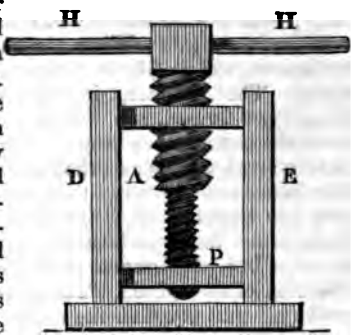
243. Since the power describes a circle, the plane of which is perpendicular to the axis of the cylinder, it acts in a direction parallel to the bases of the inclined planes, of which the screw consists. Hence [227], B being the circumference of the cylinder, and H the *pitch*, P:W::H:B.

244. There are, therefore, two methods of increasing the power of the screw: the pitch may be diminished, or the diameter of the cylinder may be increased: but the former, if carried beyond certain limits, will weaken the screw too much; and the latter may render it too gross for the object in view.

245. APPLICATION OF THE SCREW TO VARIOUS PURPOSES.—*The differential screw*, like the differential axle [192], acts by diminishing the distance through which the weight is moved, compared with that which is traversed by the power. The upper bar of a frame, DE, fig. 77, carries a hollow screw, which corresponds with the larger part of the solid screw A. P is a bar, movable only in a vertical direction, and carrying a screw, which moves up into a hollow screw contained within the screw A. When the handle HH is moved round, P is raised, or depressed; and with a force, depending on the difference between the pitch of the inner and outer screws on A. If these pitches were equal, P would, in reality, be moved neither up nor down:—for it would be raised, or depressed, by the one part of

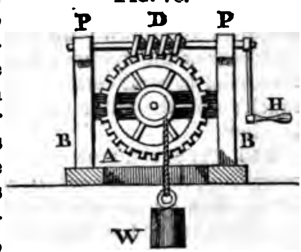
the screw just as much as it would be depressed, or raised, by the other; and the two effects would then counteract each other. But, if the pitch of the lower screw, is less than that of the upper, every revolution of HH will raise or depress P, a distance, equal to that difference: and the power will [152] be as much less than the weight, as this difference is less than the circular space, described by the power. And, since we may diminish this difference, as much as we please, without lessening the strength of the machine, we may increase its effect to any desired extent.

FIG. 77.



246. *The endless screw.*—When a screw D, fig. 78, is used to turn a spur wheel A, it is termed "endless." So many threads, only, are required, as will act upon the wheel—the teeth of which are set obliquely, that their surfaces may be, as much as possible, in contact with the screw. Such a machine has great power: since one revolution of the handle H, which is fixed on the axis of the screw, moves the circumference of the wheel through a distance equal, only, to a tooth and a space; and, when the power is relaxed a ratchet wheel [206] is not required to prevent the descent of the weight.

FIG. 78.

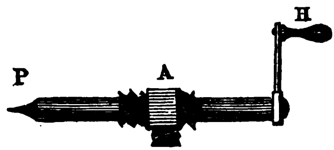


247. A wheel is never employed to turn a screw, except when waste of power is not material: as, for instance, when the screw is applied, in the musical box, to uniformly retard the motion of the works, by making air-vanes revolve with great rapidity. If the screw is used

in this way, the threads are made to approach more nearly to parallelism with its axis, that the power may be more effective in the direction of rotation.

248. *The micrometer* screw*, is an instrument used for measuring extremely small spaces. Its principle may be understood from fig. 79. While the handle H makes an entire revolution, the point P—or an index attached to it—moves through only the distance between two threads. Dividing, therefore, the circular space described by H, is really dividing the distance traversed by P. The arc through which H moves, may be measured on a graduated circle: as the circle is increased in size, the number of perceptible divisions, also, is increased: and, consequently, the number of parts, into which a space, equal to the distance between two of the threads, may be accurately divided. Every adjusting screw, is, to a certain extent, a micrometer.

FIG. 79.



The differential screw [245] has been applied to the construction of a micrometer, of sufficient delicacy to measure the millionth part of an inch.

CHAPTER III.

Regulation of Machinery—Modification of Power, 249.—The Fly-Wheel, &c., 251.—The Fuzee of a Watch, 256.—The Pendulum, 257.—The Balance, 278.—The Governor, 284.—Contrivances for changing the Direction, &c., of Motion, 287.—The Parallel Motion, 295.—The Crank, 297.—The Sun and Planet Wheel, &c., 302.—The Eccentric, &c., 311.—Velocity Combinations, 316.—Gearing, 322.—Reversion of Motion, 325.—Disadvantages incident to Machinery—Friction, 329.—Pressure of Bodies in Motion, 338.—Friction-rollers, 352.—Rigidity of Cordage, 335.

249. Regulation of Machinery—Modification of Power.—We are now to speak of the various modifications of momentum, which do not, like those we have, up

* *Micros*, small; and *metreo*, I measure. *Gr.*

to this time, examined, necessarily suppose [74] such a change of its elements as—friction, &c., not being taken into account—will leave their product unaltered. What we are about to describe, are intended to suit the force, rather to the nature, than the quantity of the work to be done; and they have not, like the mechanical powers, for their primary object, the increase, or diminution of either the mass or the velocity, belonging to a given momentum.

250. The *working point* of a machine, is that at which the power is changed, from what it is, to what the nature of the work requires it to be.

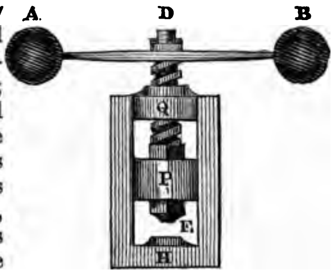
251. THE FLY-WHEEL, &c.—Many means are used to accumulate a force, which is insufficient for the purpose intended, if applied as fast as it is generated. Thus, a hammer would produce but little effect, were it allowed merely to fall by its own weight: but, being urged *continually* during its descent, it is capable of causing very considerable results, by giving out instantaneously, the force which it has been, for some time, accumulating. The bullet, which is fired from a gun, accumulates force, during the entire time the powder is exploding. Flails, whips, hatchets, &c., owe their efficiency to a similar principle.

252. But, in the arts and manufactures, the *fly-wheel* is the great magazine of motion. In many cases, the power, without being accumulated, is quite insufficient for the work to be done:—as in certain mills, for rolling metal, &c. In such circumstances, it is allowed to act on the fly-wheel for some time; and, when force enough is obtained, the metal, &c., is introduced. Sometimes, without a fly-wheel, the machinery would be injured, by sudden and great changes in the resistance. Thus, while a ponderous hammer is being raised, the motion is slow, on account of the great weight to be lifted; but when the hammer is allowed to fall, the machinery being freed from the resistance which retarded it, would, without a fly-wheel, revolve with inconvenient, and often dangerous, velocity. Sometimes, it is necessary to obtain a uniform power, from a very variable prime mover; as when steam is applied to communicate motion, through the medium of the crank. The fly-wheel changes this variable, into what may be considered as a nearly uniform force.

253. The fly-wheel is a heavy rim of metal, connected by light spokes, with the centre, on which it revolves. Its effect depends on inertia [5]. The mass is so large, that it may gain or lose a considerable quantity of motion, without its velocity being sensibly affected: the number of particles being, comparatively, so great, that when the gain, or loss, is divided between them, each has an exceedingly minute quantity.

254. For the sake of convenience, and to diminish the resistance of the air, &c., the fly is generally, though not necessarily, in the form of a wheel:—but any mass of matter would answer the purpose; and the farther it is from the centre of motion, the greater its efficiency in regulating the velocity. Sometimes—as in machinery for punching the patterns in brass fenders, &c.—the *fly* consists of two balls, A and B, fig. 80, placed at the extremities of a strong rod; and the effect is transmitted to the working point, by the screw D. A fly, with arms four feet long, and balls weighing 1 cwt. each, will, if it makes 60 revolutions per minute, urge the die against the metal to be punched, with about the same force as 7,500 lbs. falling from a height of 16 feet.

FIG. 80.



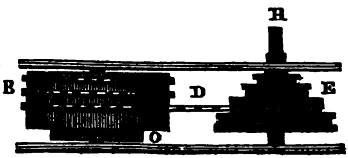
255. When a fly-wheel is intended to accumulate force, it should be placed near the power. When it is used to prevent inconvenience from sudden alterations in the resistance, it should be placed near where these alterations occur. When it is applied for the purpose of changing a varying into a uniform force, it should be as close to the working point as possible:—hence, in the steam-engine, it is near the crank.

256. THE FUZEE OF A WATCH.—When a watch is first wound up, the spring exerts too much, and when it is nearly down, too little power. In a watch or clock, the power employed should be only sufficient to supply what is consumed by friction, &c. If it exceeds that amount, it will

cause unnecessary wear and tear, by making the different parts of the works act on each other with unnecessary violence:—and it may even produce irregularity in the rate of going. The smaller the force required by a clock, or watch, to keep it in motion, the better.

If the spring were to act directly on the works, the power would sometimes be far too great:—the fuzee E, fig. 81, is intended to prevent this. It is, simply, an axle of varying diameter; which increases the leverage of the power, when it is small; but diminishes it, when the power is great:

Fig. 81.



and thus renders the motion equable. In winding a watch, the fuzee—which somewhat resembles the frustum of a cone, and has a spiral groove on its surface—is turned round, and the chain is coiled upon it, but is uncoiled from B, the cylinder which contains the spring. One extremity of the latter being attached to the inner surface of B, and the other to the fixed axis on which B revolves, it is coiled up when B is turned round. A ratchet-wheel [206] allows the fuzee to move in one way, but not in the other, without driving the machinery—since it is connected in that direction, by the ratchet, with a toothed wheel, which communicates motion to the entire train of works. When, therefore, the spring uncoils itself, by its elastic force, it coils the chain again on the cylinder, and uncoils it from the fuzee—which it causes to revolve. In reality, the curve of the fuzee is an hyperbola, its axis H being the asymptote—a line constantly approaching to, but never coming in contact with it. Some watches have no fuzee, but the barrel acts directly on the works. In this case, the thickness of the spring is gradually diminished, as it recedes from the barrel: so that its tendency to uncoil is rendered uniform, although the leverage increases as the distance from its fixed extremity is augmented.

257. The Pendulum is used to regulate the motion of clocks, &c. Its properties were discovered, accidentally, *at Pisa, by* Galileo; who remarked that a chandelier, set

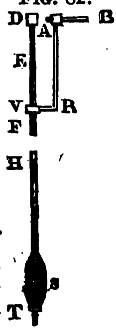
in motion by those who lighted it, vibrated in equal times. The Arabs are known to have used the pendulum, as a measure of time, for astronomical observations, so early as the year 1000 of the Christian era; although it was not applied to the same purpose, in Europe, until so long afterwards.

258. The accurate and uniform measurement of time is one of those things, which are not sufficiently appreciated, because the want of them has not been felt, for a long period. To mark the progress of time, recourse was had, formerly, to expedients, the best of which were but rude and imperfect, compared with the methods we employ. Such were the various kinds of *clepsydra*.* Also, the candles, anciently used by the Anglo-Saxons:—these contained within them, at certain distances, balls of metal, which, by successively falling into a metallic basin, gave notice that certain portions of time had elapsed.

259. Were the weight to act freely on the works of a clock, it could not be made to measure time, correctly; since it would be impossible so to adjust the power to the resistance, that the motion would be perfectly uniform. This difficulty is, however, removed by the application of the "pendulum."

260. Any body, capable of turning round on a horizontal axis, and having its centre of gravity beneath the line of suspension, is called a pendulum. If thrown out of equilibrium [97], it will ultimately return to it, of its own accord:—but in tending to recover its original position, it will move from side to side, for some time, the arcs it describes becoming gradually less, until it attains a state of rest. This motion is termed *oscillation*.

Fig. 82.



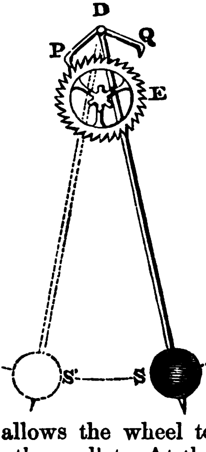
261. The pendulum, as applied to a clock, is shown, fig. 82, in a position perpendicular to the plane of vibration. It consists of a compact mass of matter, S, connected with the centre of motion, by a light and slender rod, DF, HT—supposed to be broken at F and H, that it may occupy less space in the figure. This rod is

* *Klepto*, I steal; and *hudōr*, water; *Gr.*: as they generally marked the progress of time, by the stealthy descent of water.

terminated, at its upper extremity, by a thin spring, ED, which rests in the slit made in a piece of brass D, called the *cock*. It is evident, that the pendulum does not exactly turn on D, as a centre; but that the thin spring bends freely so as to accommodate itself to the different positions, which the pendulum assumes during vibration. If it can be avoided, the cock should be attached, not to the works of the clock, but to a wall, or a strong shelf—that the "rate of going" may not be affected by a vibratory motion being communicated to the point of suspension. The pendulum is connected with the works, by the *crutch* VRA, which oscillates on a horizontal axis AB; and it passes through a fork V, with sufficient freedom to allow the sliding motion, consequent on its vibration.

262. Fig. 83 represents a pendulum, in the direction of the plane in which it moves. Pallets P, and Q, are fixed on the axis D—which corresponds with AB, fig. 82—and act, alternately, on the *escapement wheel* E. The latter is called, also, the *swing wheel*, and, along with the pallets, is termed the *escapement*, or *'scapement*. When the pendulum reaches either extremity of its arc of vibration, it checks, by its inertia, through the medium of one of its pallets, the motion of the swing wheel; and, consequently, arrests the action of the moving power—causing the whole train to stop for a very short period. The tendency of the pendulum to vibrate in the opposite direction, disengages the pallet, and allows the wheel to move, until it is again stopped by the other pallet. At the moment each pallet is being disengaged, it receives a slight impulse from the swing wheel, which replaces the motion lost by friction, &c.

FIG. 83.



263. Two vibrations of the pendulum cause the swing wheel to move through the space of one tooth. If, therefore, it has 30 teeth, with a pendulum vibrating seconds, it will make one revolution in a minute.

264. The "centre of suspension" of a pendulum, is that point, around which, as a centre, it moves. The centre of oscillation, is that point in a body, or a system of bodies, into which if the whole mass were compressed, a given force would cause it to revolve with the same velocity as that at which it would make the body, or system of bodies revolve. If all the parts of an oscillating mass could vibrate separately, those nearest to the point of suspension would vibrate more quickly than those farther from it. But, as the whole mass must vibrate together, it must vibrate with an intermediate velocity. That point where its velocity is neither accelerated nor retarded is called the "centre of oscillation." And, if the whole mass could be compressed into this point, the rate of vibration would not be changed. It is the action of gravity which makes the pendulum continue to oscillate, for some time after the force of gyration has ceased to operate. The centre of gyration of a body, or of a system of bodies, revolving round a fixed axis, is that point at which, if the whole mass were compressed, it would revolve with the same velocity as the body or system of bodies.

265. The properties of the pendulum depend on the principles which relate to bodies falling down an inclined plane, and which we have already explained [230, &c.] But for the resistance of the air and friction, a pendulum after having fallen down the curve—in which it is kept by a string, rod, &c.—would rise to the same height, on the opposite side; and, once put in motion, would continue to oscillate for ever.

266. Since, as we have already shown [236], bodies descend in equal times through unequal arcs of the cycloid, many contrivances have been devised, to make the pendulum move in that curve; but they have not been found convenient in practice. The pendulum, therefore, generally vibrates in *small* circular [232], or nearly circular [261], arcs. It is suspended, in various ways, but is, most ordinarily [261], attached by a thin spring.

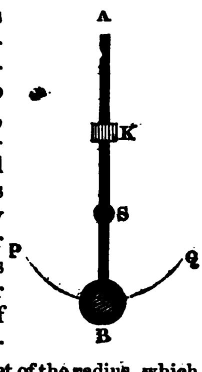
267. If the force of gravity is supposed to be constant, "the time of oscillation varies as the square root

of the length of the pendulum."* Hence, one that is four times as long as another will vibrate twice as slowly.

268. The *length* of the pendulum is the distance between the centres of suspension and oscillation, and is obtained, "by dividing the square of the distance of the centre of gyration from the centre of suspension, by the distance of the centre of gravity from the centre of suspension." But we may find it practically—as suggested by Captain Kater—if we find some other point, which being made a new centre of suspension, will leave the rate of vibration unchanged. This will be the centre of oscillation; since the centres of oscillation and suspension are commutable. And the distance between the two points of suspension, will be the *length* of the given pendulum. If a right angled cone—that is, one the diameter of whose base is equal to its altitude—is suspended by its vertex, its centre of oscillation is the centre of its base: but, if it is suspended by its base, its centre of oscillation coincides with its vertex.

269. It is evident that we increase the *length* of the pendulum, by diminishing the distance between the centres of gravity and suspension:—since decreasing the divisor, increases the quotient. We may, therefore, increase its length, without altering the mass of matter which it contains. The construction of the *metronome* is founded on this principle. It is an instrument used for measuring *musical* time, &c.; and consists of a pendulum, AB, fig. 84, having a heavy knob of brass, B, attached to a slender rod, and a movable knob, K, which is capable of a sliding motion, between A and the point of suspension, S. When K is raised, or depressed, the centre of gravity of the whole is raised up towards S, or is moved down from it; which causes the pendulum to oscillate with less, or greater rapidity. When the centre of gravity is brought nearer to S, its lever-

FIG. 84.



* For [233 note] T varies as the square root of the radius, which, in this case, is the length of the pendulum.

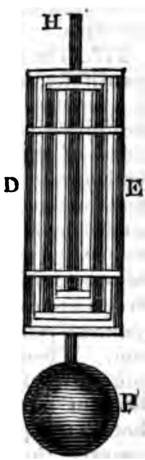
age, and, by consequence, its efficiency in overcoming the inertia of the pendulum, is diminished. A pendulum vibrating

Seconds.	Inches.	Seconds.	Inches.
¼ must be	. 2·44616 long.	1 must be	. 39·13860 long.
½ „	. 9·78465 „	2 „	. 156·55544 „

270. It is very important that the arcs of vibration should be small [235]. A seconds' pendulum would require 1·0736″, to describe an arc of 120°; and 1·18″, to describe a semicircle.

271. The pendulum cannot be an accurate regulator of time, unless it is always of exactly the length which is suited to the place. If a seconds' pendulum is made the tenth of an inch shorter, it will gain 114″ in 24 hours. If one that vibrates seconds, at London, is carried down into the mine at Dolcoath in Cornwall—which is 1,050 feet under the level of the sea—it will require only 0·99997″, to make one vibration; but, if it is carried to the summit of Mont Blanc —which is 15,780 feet above the level of the sea—it will require 1·000753″.

FIG. 85.



272. The pendulum is very much altered in length, by changes of temperature. For it is found that one made of iron, which, on a cold day, would regulate a clock with perfect accuracy, on a hot day, will make it lose several seconds.

273. Many contrivances have been devised, for counteracting the changes due to temperature. Among others the *Gridiron Pendulum*, HP, fig. 85. It consists of a combination of rods, of different metals; which are so arranged, that, when some of them, by expanding in one direction, raise the bob, P, the others, by expanding in the opposite, depress it. The rods which require to be longest, are made of the less expansible metal: that the two opposite expansions may be equal.

274. *The Mercurial Pendulum*, RE, fig. 86, is another of these contrivances: it has been long in use; and is, at present, very commonly adopted. Mercury, contained in the glass cylinder D, expands with the

FIG. 86.

increase of temperature, and raises the centre of gravity of the pendulum—which, on the other hand, is depressed by the expansion of the rod RR. There is an adjusting screw P: and an index H, to mark, upon a graduated arc, the extent of vibration.

275. A piece of straight grained deal, boiled in a chandler's vat, and gilt, is found to make a pendulum rod, but little affected by atmospheric changes.

276. Since the pendulum acts by the force of gravity, which varies, at different distances from the earth's centre [70], it enables us to measure the height of mountains, by ascertaining how its rate of vibration is changed, when it is brought to their summits.

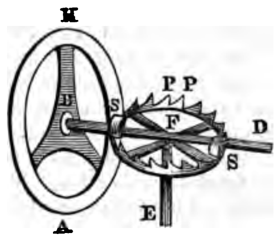
The intensity of the force of gravity, at a given place, is deduced from the number of oscillations, made there by the pendulum, before it returns to a state of rest, after being set in vibration.

277. The oscillation of the pendulum is employed very beautifully, to exhibit the rotation of the earth on its axis, in a manner obvious to the senses. A heavy metallic ball, carefully turned—that its shape being symmetrical, and its centre of gravity in the centre of its mass, it may have no tendency, in passing through the air, to move round a vertical line, or otherwise interfere with oscillation—is suspended by a long and slender wire or cord, from a dome, steeple, or some other lofty building, an index being attached to it, so as to point downwards: and concentric circles are drawn on the floor or a table underneath, their common centre being directly under the point of suspension. When this pendulum is put in motion, it will continue to oscillate for many hours; and its index will cut different portions of the horizontal circles successively: that is, the plane of vibration will seem to rotate. It is, however, the floor or table, on which the concentric circles are described, that moves round, on account of the diurnal motion of the earth. This revolution is not indeed performed round the centre of the circles; but the floor or

table revolves, along with the earth, round the earth's axis. A little consideration, however, will show that, as far as the senses are concerned, the effect is the same; and is due, not to the plane of vibration remaining altogether unchanged, but to its continuing parallel with itself, while the point, from which it is suspended, is carried round. The motion of the plane of vibration, in azimuth, will, it is clear, not be uniform, unless with a pendulum suspended actually at a pole of the earth; at the equator it will not have any motion. The revolution of the plane of vibration, takes place in a period exceeding 24 hours—being retarded to a greater or less extent, according to circumstances.

278. THE BALANCE.—It would be impossible to apply the pendulum to a watch, chronometer, &c. Yet these, also, as well as clocks, require some mode of uniformly checking their prime movers. This is effected by the *balance*, which was employed as a kind of fly-wheel, even before the pendulum, to regulate instruments for measuring time. The balance of a watch, &c., consists of a nicely poised wheel A—fig. 87, that plays on pivots turning in holes, which to prevent the wear arising from the rapid motion, are drilled in steel, diamond, or some other very hard substance; and it is connected with a fine spring, called the *hair*, or *pendulum spring*. When the balance is turned round, in one direction, the hair spring is coiled up; but being immediately uncoiled, by its elasticity, it moves the balance, to an equal extent, in the opposite direction. Pallets, fixed on the axis of the balance—termed the *verge*—act on the *crown-wheel* of the watch, just as the pallets of the pendulum act on the *swing-wheel* of the clock [262]:—and also receive impulses from it, while being disengaged, which replace the motion, lost by the balance on account of friction, &c.:—and thus the vibrations are continued.

FIG. 87.

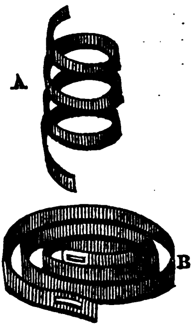


279. The "hair spring" may be either a flat helix,* the

* *Helix*, a spiral. Gr.

coils of which diminish as they approach the centre; or one, the coils of which are all equal in size. The former, occupying less space, is used in watches; the latter, being more regular in its action, is applied to chronometers. A flat helix may be understood from B, fig. 88, which represents the mainspring of a watch: and the other species from A.

Fig. 88.



280. With a hair spring, of a given thickness, the rate of vibration depends on its length:—that is on the distance between the point at which it is attached to the axis of the balance, and the place where it passes through a notch, cut in a stud —connected with what is called the *regulator;* the *absolute* length of the spring being of no consequence. When the regulator is moved in one direction, so as to increase the vibrating length of the hair spring, the watch goes more slowly; and when, in another, so as to shorten it, the watch goes faster. The hair spring is diminished in thickness [256], as it recedes from the fixed point, that its tendency to coil and uncoil may be as uniform as possible. This adjustment is not required, unless the spring is a flat spiral: hence the latter is used in chronometers.

281. Since the balance of a watch acts as a fly-wheel [253], its effect depends on the quantity of matter contained in its rim, and on the distance of that rim from the centre of motion:—altering either, or both of these, would alter the rate of going, since it would give the hair spring more, or less work to do, in moving the balance; and would, therefore, cause the oscillation to be more, or less rapid. This affords another method of regulation: which is, however, chiefly confined to chronometers. Screws, with comparatively large heads, are fixed in the rim of the balance; and according as these are moved in, or out, the mass of the rim is brought nearer to, or farther from, the centre of motion.

282. It is necessary that the hair spring once regulated, should continue to be of exactly the same length; and that the *mass of the balance,* should remain at the same distance from

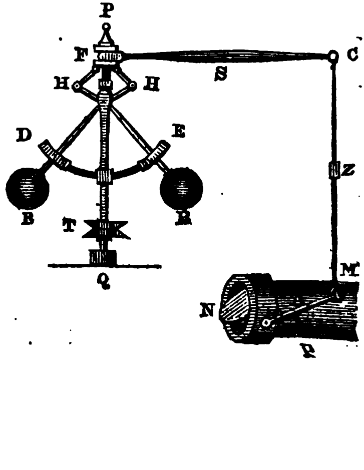
the centre of motion. But since the fulfilment of these conditions, however desirable, is prevented by changes of temperature, many methods of constructing "compensation balances" have been devised. They are similar, in principle, to the gridiron pendulum [273]: but none of them is so important, as to render a description requisite. A well-constructed ordinary watch, is a sufficiently good regulator of time, for most purposes.

Sometimes the plane of the *balance-wheel*—or that, upon which the pallets act—is perpendicular to the plane of the dial; the movement is then said to be *vertical*. Sometimes it is parallel with the dial; and it is then *horizontal*. The latter arrangement, in conjunction with certain contrivances, into the details of which it is not necessary for us to enter, allows the balance to swing through a larger arc, and thus the rate of going is more effectually regulated.

283. If it is necessary to check the action of a prime mover uniformly, and without stopping its effect, even for short periods: the pendulum is then inapplicable. Hence a *fly* or *fan* is used, in musical boxes, in the striking part of clocks, &c.: being made to revolve with very great rapidity, it meets with such resistance from the air, as retards the motion of the machinery with which it is connected.

Sometimes the fan is so arranged as that, by turning it on an axis, it may be made to displace a larger, or smaller quantity of air, during its revolution—and thus to exert a greater, or less retarding power.

FIG. 8 9.



284. THE GOVERNOR.—When the resistance to be overcome is variable, to an extent which would seriously affect the rate of the fly-wheel, water-wheel, &c., the power itself, also, must be varied. The "governor" or conical pendulum [126] is used for this purpose, when the prime mover is steam;

and, sometimes, also, when it is water. It consists of two rods, carrying heavy balls, B, B, fig. 89, and attached to a rod PQ, which is made to revolve by means of the pulley T, driven by the power. The pendulums are carried round by PQ: and, when the velocity of rotation exceeds a certain amount, they are thrown out by centrifugal force: their increased divergence then depresses the fork F, lying in a grooved ring, which is movable up and down, on PQ, and is so attached, by joints, to the pendulums, that it is lowered, when they rise: and elevated, when they fall. The fork F is at the extremity of a lever FC, turning on some point S. When F is depressed, the rod CM is raised: and, by means of the arm A, the throttle valve N is closed—to an extent, which depends on the velocity with which the governor revolves. The length of CM, is adjusted by a simple contrivance at Z. The details of the governor are variously modified, according to circumstances; but its mode of action will, in all cases, be easily understood, from what we have said.

When the velocity of rotation becomes less than it should be the pendulums fall, and the throttle valve is opened.

285. The farther the balls recede from the axis of rotation, the greater the centrifugal force, with a given number of revolutions per minute, and the greater the tendency to fly out. But this is nearly counteracted, by the increased effect of gravitation: so that, after a temporary derangement of speed, the governor will return very nearly to its original velocity. A sudden and undue change of speed, however, in the engine, causes the balls to fly out too much; this checks the motion of the engine, and they collapse beyond the proper amount. They will next diverge too much, and afterwards collapse—these alterations continuing, but gradually decreasing, until the engine acquires its proper rate of going.

286. If the governor is attached to a water-wheel, the rod FC, fig. 89, throws into action machinery which, by means of power derived from the wheel itself lifts or depresses the sluice-gate—so as to increase or diminish the supply of water; and therefore, to increase the power, or lessen it, to the required extent.

When the supply of water is precisely what it should be, to overcome the resistance, the rod FC holds such an intermediate position, as leaves it unconnected with the machinery intended either to raise or depress the sluice.

Fig. 90.

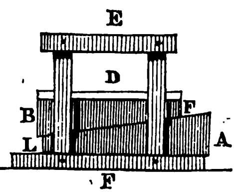
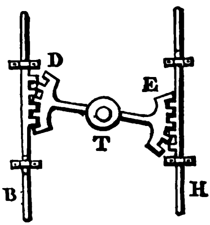


Fig. 91.



287. **Contrivances for changing the direction, &c., of Motion.**—*Change from one direction to another. Two wedges*, fig. 90, may be used for this purpose. When the lower one is driven in the direction AL, the upper one raises any thing placed upon it, in the direction FD.

288. *Two racks and segments.* When one rack H, fig. 91, is raised or depressed, the other rack B will be depressed, or raised, by the segment D.

Altering the radii of the segments, will modify the relative velocities of the power, and resistance.

289. If there are only one rack, and one segment reciprocating rectilinear motion, in one direction, will produce reciprocating circular in another: and *vice versâ.*

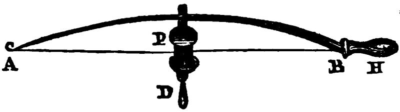
290. *The Bell-crank* or angular lever, exemplified, fig. 26, will alter the direction of motion, and modify the relative velocities. The arms may be of any lengths, and form any required angle.

291. The pulley [178], and wheel and axle [191], will change the direction of motion. Also several of the contrivances to be described immediately: indeed many of them may be applied to more purposes than one; as a little consideration will show:—for instance, they may, sometimes, be made to produce two changes of motion, exactly the reverse of each other. This must be kept in mind.

292. *Reciprocating rectilinear changed into reciprocating circular motion.* Besides the racks and segments [288], we may use the *drill and bow*, fig. 92. When by means of the handle H, the bow is moved from A to B, or from B to

A, the pulley P is carried round; and, pressure being applied above the drill, D, it enters the substance to be pierced.

Fig. 92.



293. Another contrivance, represented fig. 93, is often employed for the same purpose. It consists of a circular weight W, fixed on a spindle AB; a cord, attached to the inner extremities of the handles E and F, passes through the upper part of the spindle—which turns freely, in H, an aperture of the bar EF: the drill D is fitted to the spindle at B. The point, A, being placed in the hollow, made for it at the centre of a plate, which is held to the breast, &c., the drill is pressed against the spot where the aperture is to be made: and—the spindle having been turned round, so as to coil the cord upon it as represented—the bar EF is pushed strongly towards D, by means of the handles E and F. This will first uncoil the cord, which, the spindle being carried round by the weight W, will then be coiled in the opposite direction. And thus, by continuing at the proper times, to force the bar EF, along AB, a reciprocating circular motion may be produced: and, the pressure being maintained at A, the drill D will bore with great facility.

Fig. 93.

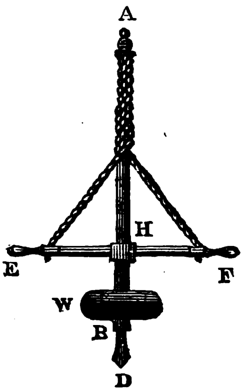
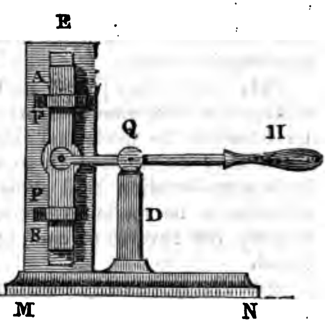


Fig. 94.



294. If the handle H, fig. 94, is moved up and down, the bar AB, will be depressed and raised, in the guides P and F, by means of a pin, fixed in the rod to which the handle H is attached, and working freely in a *slot*—or opening, formed transversely in the middle of AB.

295. THE PARALLEL MOTION was invented by Watt, for the purpose of keeping the piston perfectly parallel with the axis of the steam cylinder, while communicating a reciprocating rotary motion to the extremity of the beam. It is founded on a geometrical principle, which may be understood from fig. 95. Let CE be a rod, turning on C, as a centre; and DF, another rod, turning on D. Let EF, be a rod attached to CE, by a joint E, and to DF, by a joint F. If the points E and F are made to describe arcs not exceeding a certain length, P, a point in the connecting rod, exactly between them, while moving up and down, will always be found in the right line NH. Any thing, therefore, attached to P—for example, a pump-rod—will be moved exactly in the direction NH. This principle is applied to the steam engine in various ways, which may be understood by a single example, fig. 96. DF, a portion of the beam, occupies the place of the rod, indicated by the same letters, in fig. 95: the rods CE and EF, also correspond, in both figures. Hence any thing attached to P, will be found, continually, in the same right line.

FIG. 95.

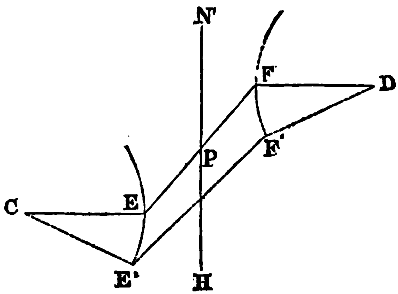
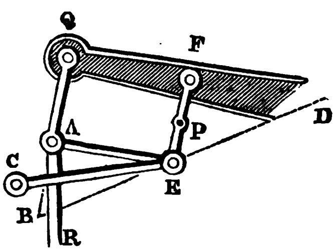


FIG. 96.

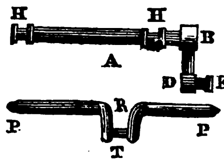


And, since the triangles DFE and DQB are similar, the point A will move parallel to the point P:—and consequently, will always be found, as well as any thing attached to it—for instance, the piston rod—also, in the same right line. The dotted lines are introduced into fig. 96, merely for the purpose of explanation; but they form no part in the parallel motion.

296. Strictly speaking, the point P, figs. 95 and 96, does not move in a straight line, but in a curve—which, however, deviates so little from a right line, as, in practice, to cause scarcely any inconvenience.

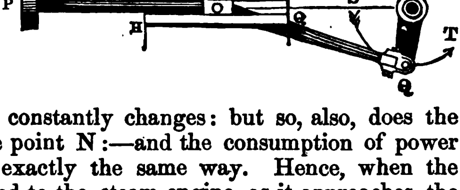
297. *Reciprocating Rectilinear, changed into continued Circular Motion.*—THE CRANK, fig. 97, the contrivance most commonly employed for this purpose, is a short arm or lever BD, placed at the extremity of the shaft, or axle —as in certain kinds of steam engine; or, at RT, between the extremities of the shaft, or axle—as in the turning lathe, &c.

FIG. 97.



298. The crank is often said to destroy power. But it is evident, from the very nature of the lever [175], that, although, when it is employed, the mass of the resistance continually varies, its momentum—friction, &c., not being taken into account—is always precisely equal to that of the power. As the crank approaches the *dead points*—one of which is at S, fig. 98—the action of the power becomes merely a strain on the axle, no part of it being exerted in moving the crank round. The mechanical effect, therefore, constantly changes: but so, also, does the velocity of the point N:—and the consumption of power is altered in exactly the same way. Hence, when the crank is applied to the steam engine, as it approaches the dead points, the motion of the piston P, and, consequently, *the expenditure* continually decreases. The elements of

FIG. 98.



the momentum of the crank constantly vary when the force is uniform, but the momentum itself is constant.

299. Although the crank does not destroy power *directly*, it destroys it *indirectly*. This arises from what is called the "obliquity of the connecting rod." Power is invariably lost, when [122] it is not applied *exactly* in the direction in which it is intended to produce motion:—which occurs, when the crank is to be moved by steam. The piston rod, fig. 98, exerts a force in the direction AB: while the motion, required to turn the crank, is tangential to the curve at Q. If, therefore, the hypothenuse represents the whole power, a small side will [132] represent its effective part. And that amount of it which merely strains the axle; &c., will be to the whole :: one of the small sides: the hypothenuse. Thus, it is evident that the power is not entirely effective in turning the crank round, at any part of its revolution: and that the relative amount of the ineffective part constantly varies.

300. A fly-wheel is required, to carry the crank over the dead points; and, also, to render the velocity, with which it revolves, uniform. But the mechanical effect of the crank is thus made constantly to vary, from 0 to maximum, and from maximum to 0: which, though at first sight it appears a great inconvenience, is, in reality, the most important advantage derived from its application to the steam engine: since, by means of it, the motion of the piston, &c., is gradually retarded, as it approaches to, or recedes from, the dead points; and the violent shocks and strains of the machinery, which would arise from *suddenly* stopping, or bringing into rapid motion, so large a mass of matter as the piston rod, beam, &c., of powerful engines, are completely avoided.

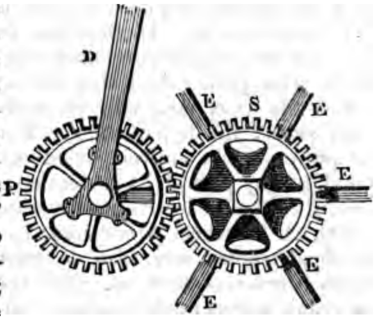
301. When the fly-wheel is inapplicable—as with locomotives, &c., the inconvenience arising from the dead points, is obviated by the use of two engines, the cranks of which are fixed at right angles on the same axle; so that when one is at a dead point, the effect of the other is at a maximum; and their joint action is very uniform.

302. The Sun and Planet Wheel, &c.—The application of the crank to the steam engine, by Watt, was betrayed through one of his workmen, to a gentleman of

Bristol, who took out a patent for it. It was, however, used long previously, to change reciprocating rectilinear into rotary motion: and its application to the steam engine was patented, several years before Watt's experiments, by Jonathan Hill:—but the patent seems to have been forgotten.

303. Watt, to avoid litigation, adopted, instead of a crank, the "sun and planet" wheel, fig. 99, which is, in reality, a *concealed crank*. S and P are two equal wheels, connected by an iron band; the former being, from the nature of its motion, called the *sun;* and the latter the *planet* wheel. S revolves on its centre; but P is fixed, immovably to the rod D. P, in going round, moves S; but, when it has made half a revolution, it has driven that tooth of S, with which it was, at first, in contact, one half a revolution—by the action of its teeth, and another half revolution—by its motion, round S. The axis, therefore of S, and the fly-wheel, &c., attached to it, make twice as many revolutions as if a crank were used.

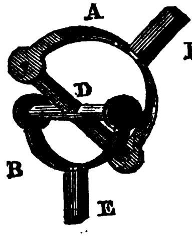
FIG. 99.



The crank is now, almost exclusively employed.

304. *Circular Motion, in one direction, changed into Circular in another.—Hook's universal joint* will change the direction of circular motion. In its simplest form it consists of two forks, A and B, fig. 100, in which pivots, at the end of the cross D, turn freely. When the shaft E revolves, the shaft F—making some angle with E—is made to revolve, *also. This contrivance* sometimes

FIG. 100.

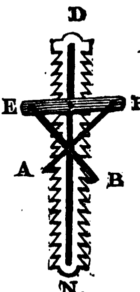


assumes a more complicated form. It is used, occasionally, instead of bevelled wheels [203].

A spur wheel, working with a crown wheel [199, &c.]: a wheel and endless screw [246] &c. are used, likewise, for effecting a change in the direction of circular motion.

305. *Reciprocating Circular, changed into continued Rectilinear Motion.—The lever of Lagaroust*, fig. 101, may be employed for this purpose. Hooks, A and B, are moved up and down, by means of the lever EH, turning on a stationary pin, which passes through a slot cut in DN—to allow it a motion upwards and downwards. While one hook is lifting DN, the other is descending into the next tooth.

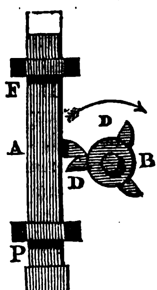
FIG. 101.



306. *Reciprocating Circular, or Rectilinear, changed into continued Circular in either direction.*—A toothed wheel may be moved through one or more teeth at a time, by a ratchet [206], the lower extremity of which is shaped so as to drop between the teeth, and which receives from a lever, &c., a reciprocating motion, in a circle concentric with the wheel, or in its tangent.

If the ratchet is double, and properly placed, it will communicate motion in the opposite direction, by merely throwing it over on its centre. The ratchet is very often, and conveniently, applied in this way.

FIG. 102.



307. *Continued Circular, changed into Reciprocating Rectilinear Motion.*—A beam, A, fig. 102, having a projecting shoulder, may be lifted by means of a wheel B, on which there are fixed any required number of wipers, D, D, &c. As B revolves, the wipers come, successively, into contact with the projecting shoulder, and lift the beam. When each wiper is disengaged, the beam falls by its own weight. The stampers of oil mills, are often worked in this way.

308. If it is necessary to produce rectilinear motion, in the *two* directions, by the apparatus itself, we can use the

wheel D, fig. 103, carrying pins—with or without friction rollers—which, acting on a single tooth in each rack, successively raise and depress XZ, in the guides O and Q.

309. The alternate motion may be rendered *continuous*, by means of the contrivance, fig. 104. The eccentric disc H, as it revolves within PF, raises and depresses AB, in the guides D and E. The motion of AB is rendered *uniform*, by using a wheel, fig. 105, containing teeth, on only

FIG. 103.

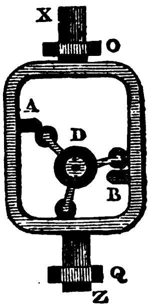


FIG. 104.

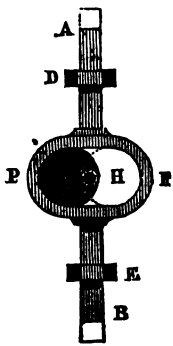
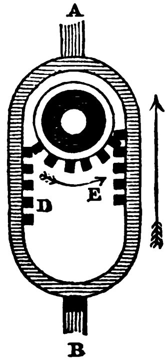


FIG. 105.



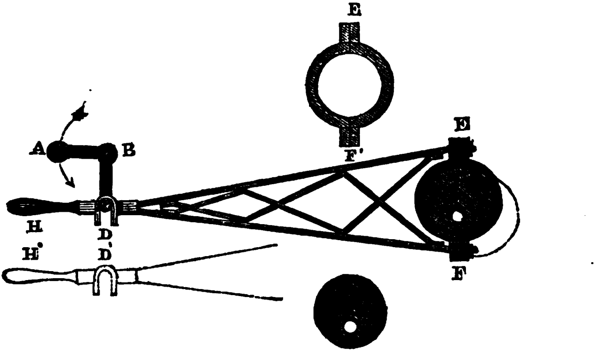
a portion of its circumference:—during revolution, these teeth, acting alternately on the racks D and E, alternately raise, and depress AB.

310. If an annular wheel [200] is rendered immovable, and a spur wheel, of half its diameter, is made to work within it, the centre of the smaller being made to describe a circle round the centre of the larger wheel, any point in the circumference of the smaller, will be found, continually, in the same diameter of the larger; and any thing attached to that point will move backwards and forwards in a right line.*

* This may be easily shown geometrically. Let the larger circle, fig. 106, represent the annular wheel; and the smaller one the spur wheel: and let A be the point of contact of the two. If the smaller have moved from the position indicated by the dotted circle, that point of it which was, at first, in contact with the larger wheel, has moved to P, in the same diameter of the larger. For, the arcs DP and DA are equal; since the one is the measure

311. THE ECCENTRIC is a very common, and convenient contrivance, for producing reciprocating rectilinear from rotary motion. It is a species of crank; but it does not weaken the axle, by causing it to be of an angular form:—

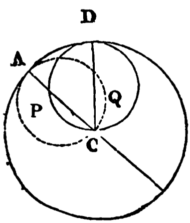
FIG. 107.



and it is, besides, applied more easily than the crank. It consists of a disc P, fig. 107, turning along with the axle to which it is attached, but with which it is not concentric. The distance between the centre of the crank and the axis of the axle, is called the *throw* of the crank. A circular strap EF, works on P; and is made in two parts that, as it wears, it may be tightened by means of screws at E and F. The disc and strap cannot separate, since one of them plays in a groove which is formed in the other. As the eccentric revolves in the strap, HD is moved backwards

of the angle ACD, which is "central" with reference to the larger circle and the other is double the measure of the same angle, which is "inscribed" with reference to the smaller. Hence DP contains twice as many degrees as DA. But—since circles are proportional to their radii—any number of degrees, in one, will be equal in length, to double that number in another, the radius of which is only half as great.

FIG. 106.



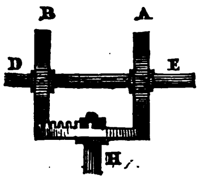
The same reasoning would show that the *point of the smaller wheel, originally in contact with the larger, will be found, successively, in every other point of the same diameter of the larger.*

and forwards. And if ABD is a bell crank [161] moving round B, a reciprocating motion will be communicated to A. The valves of many steam engines are worked in this way. The different parts of the apparatus are shown separately, also, in fig. 107.

312. *Continued Rectilinear, produced by continued Rotary Motion.*—This may be effected by a wheel or pinion, working into a single rack [289]. Also, by a solid and hollow screw [242]: if one of these is movable in a direction parallel to its axis, and the other is not so, any thing attached to the former will be carried along with it, when the latter is turned round.

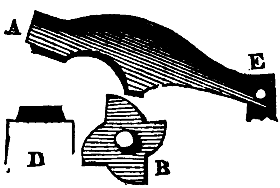
313. *Continued Circular changed into Reciprocating Circular Motion.*—We may use, for this purpose, the crown wheel H, fig. 108, having teeth on only a portion of its circumference, and working with the spur wheels A and B. As H revolves, it acts alternately and in opposite directions, on A and B; and a reciprocating circular motion is produced, in the shaft DE.

FIG. 108.



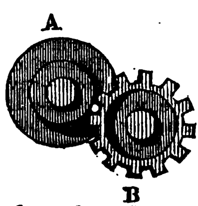
314. A wheel B, fig. 109, carrying any required number of wipers, will communicate a circular motion to the hammer A. As B revolves, the wipers, in succession, raise the hammer which, when the wipers become disengaged, falls by its own weight.

FIG. 109.



315. *Continued Circular, producing continued Circular Motion, in the same, or in a different direction; and having the same, or a different velocity.*—The wheel and axle [191], drums [196], bevelled wheels [203], &c., may be used to produce this kind of change in circular motion.

FIG. 110.

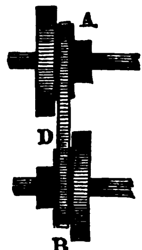


Or let there be a pin, on one of the lateral surfaces of

the wheel A, fig. 110. When A is made to revolve, the pin, coming successively into contact with the teeth of B, will make it revolve also. It will revolve but once, however, during as many revolutions of A, as there are teeth.

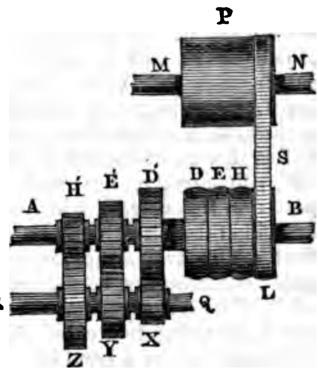
316. VELOCITY COMBINATIONS.—It is often of great importance to alter permanently, or temporarily, the velocity with which machinery is driven. Many contrivances are employed, for the purpose: but we shall describe a few, only, of the most important. We may use drums A, and B, fig. 111, each containing pulleys of different diameters, and of such proportions, as that those which are opposite, may, by the same band, be made to work together—the band being changed, with ease and rapidity, from one pair to another.

FIG. 111.



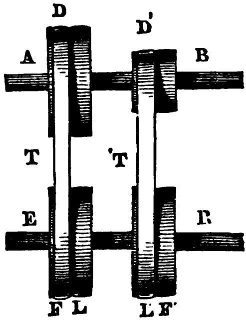
317. We may also employ the contrivance represented fig. 112, P is a drum driven by the prime mover. AB is a shaft, on which four pulleys and three spur wheels, of different diameters, revolve. The pulley H and the spur wheel H′ are fixed immovably to the axis AB. The pulley E is immovably attached to the spur wheel E′, by a hollow axis turning freely on AB. And the pulley D is immovably attached to the spur wheel D′, by a hollow axis turning freely on that which connects E and E′. The *loose pulley* L, turning freely on AB, is used for a purpose to be described presently. X, Y, and Z are keyed on the shaft Q. If the band from P is thrown upon H, H′ will move Z:—Y and X will then keep E′ and E, D′ and D, revolving; but, being loose on AB, they will produce no effect. If the band is thrown on E, E′ will move the smaller wheel Y:—RQ will, thus, be made to revolve with

FIG. 112.



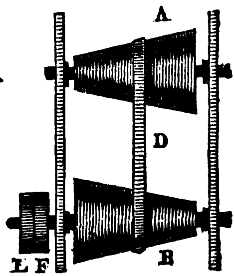
greater speed, Z and X will, in this case, keep H′ and H, D′ and D revolving: but, without producing any effect. If the band is, lastly, thrown on B, D′ will move the still smaller wheel X:—RQ will, then, revolve with still greater speed. In this case Z and Y will keep H′ and H, E′ and E revolving.

FIG. 113.



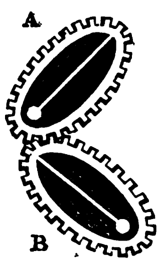
318. A similar effect may be produced without the aid of toothed wheels, by the arrangement, fig. 113. D and D′ are drums, fixed immovably, on the shaft AB, which is driven by the prime mover; F is a pulley, fixed immovably on the shaft ER, and L a pulley, turning freely upon it; F′ is a small pulley, also fixed immovably on ER, and L′ a pulley, turning freely upon it. If the band T is thrown on F, and T′ on L′, ER will be made to revolve:—D′ will keep L′ revolving; but, being loose on the axle, it will produce no effect. If T is thrown on L, and T′ on F′, ER will revolve, but with less speed: in this case, T will keep L revolving: but it will produce no effect. The two straps may, by simple contrivances, be shifted together.

FIG. 114.



319. The velocity may be *gradually* varied, by using two cones A and B, fig. 114, connected by a band D. If A is driven by the prime mover, B will revolve and with greater or less speed, according to the position of the band. When the latter is gradually moved in one direction or the other, the speed will be gradually changed.

FIG. 115.

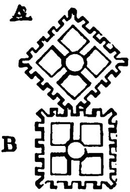


320. *Elliptical Wheels* A and B, fig. 115, will, if made to work with each other, *produce a varying* velocity. Each is sup-

posed to revolve on one of its foci. If the larger part of A acts on the smaller part of B, B's velocity will be greater than that of A; but it will be less, if the smaller part of A acts on the larger part of B.

321. *Square Wheels* A and B, fig. 116, will, when working together, produce a velocity which varies from greatest to least, four times during every revolution of either wheel.

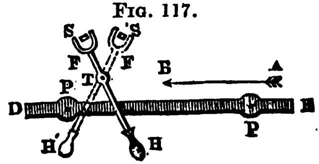
FIG. 116.



322. GEARING.—It would often be attended with the greatest inconvenience, if it were necessary to stop the prime mover, as often as any part of the machinery must be brought to a state of rest.

Fast and Loose Pulleys.—Machinery may be connected, or disconnected, by what are called "fast and loose pulleys." They consist of two pulleys, placed together on the same shaft, only one of them—the *fast* pulley—being keyed upon it. When the band is thrown on the loose pulley, the latter will revolve without the shaft, or the shaft without the pulley. From the tendency of a band, to get upon the centre of the slightly convex rim of a pulley, it is very easy, by means of a *fork* worked with a lever, to throw it from one pulley to the other. This is effected, when the machinery is *self-acting*, by some part of itself. For instance, let S, fig. 117, be a section of the band, which is to be thrown from a fast to a loose pulley. When DE has—by means of the power—been carried along through a certain space, which is regulated by the position of the pins PP, the fork HS, turning on T as a centre, being acted on by one of the pins, shifts the bands from a fast to a loose, or from a direct to a reversing pulley—or *vice versâ*. When it is necessary to move the fork rapidly, a weight is so applied as that, falling suddenly over at the proper times, it accelerates the motion of HS. Fast and loose pulleys are seen in fig. 112—the former being represented by L, and the latter by D, E, and H. Also, in fig. 113, the former being represented

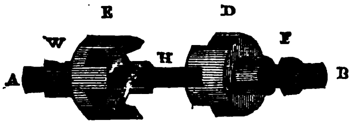
FIG. 117.



by F and F′, the latter by L and L′; and in fig. 114, the former being represented by F, and the latter by L.

323. *Clutches*, also, are contrivances intended to throw machinery in, or out of gearing. They are of various kinds; but may be understood from fig. 118. A small disc D contains projections and spaces; which correspond with, and fit into spaces and projections in E—attached, for example, to a wheel, within which the shaft AB revolves freely. The disc D is capable of being moved along the shaft, by means of a fork, working in the circular groove F; but, since it has a pin, which projects into a longitudinal groove in AB, the latter cannot revolve without making it revolve also. The discs being as represented in the figure, it is evident that AB and D will revolve, without carrying E along with them. But if D is moved on the shaft, until its projections enter the spaces of E, the rotary motion of AB will be immediately communicated to it. If the fork F is brought back again, D and E being no longer connected, the rotary motion of the latter will cease—although AB continues to revolve.

Fig. 118.

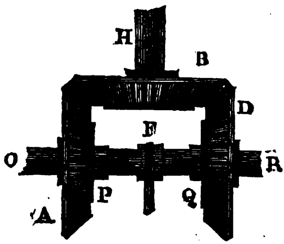


324. When a clutch, fig. 118, is used, the solid parts of the machinery coming *suddenly* into contact, the inertia of the quiescent portion offers a resistance to motion, which, since it is not gradually overcome [6] is the cause of great strain and wear. To obviate this inconvenience, clutches have been devised, which—acting by friction—allow the machinery to slip, more or less, until it gradually acquires the proper velocity.

325. Reversion of Motion.—If it is necessary, with a force acting constantly in the same direction, to move machinery, sometimes in one, and sometimes in the opposite direction, the contrivance represented, fig. 119, may be employed. A, B, and D are bevelled wheels. A and D allow the shaft O R to revolve, without being moved by it. There are portions of clutches at P and Q; and a fork, which works in the circular groove of F—containing the counterparts of P and Q—and which re-

volves with the axle, but is capable of sliding along it. When F is in the position represented, it revolves in the fork, without moving any of the bevelled wheels. But if the fork is moved along OR, F locks in the counterpart P, or Q, attached respectively to A and D:—this causes A or D to revolve, along with the shaft, and to move B in one direction, or in the *opposite*. While either A, or D is driven by the shaft, the other revolves freely upon it—producing no effect.

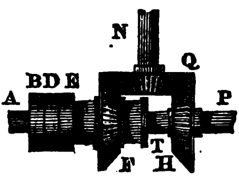
Fig. 119.



326. If H, the shaft belonging to B, fig. 119, carries a pinion, which works in the rack attached to a sluice gate, and F is moved by the governor, the quantity of water supplied to the wheel, may be rendered always proportional to the amount of power required [286].

327. A very convenient reversing apparatus is represented, fig. 120. B, D, and E are pulleys; F, Q, and H, bevelled wheels. D is loose. B, and H are fixed immovably on the shaft AP. E and F are attached to a hollow axis, which allows AP to revolve freely within it. When a band, connected with the prime mover, is thrown on B, the bevelled wheel H and the shaft AP revolve; and Q with its shaft N is moved in one direction, E and F being moved also, but producing no effect. If the band is placed on E, the bevelled wheel F revolves; and Q, with its shaft N, is moved in the opposite direction, B and H being moved also, but producing no effect. The band being thrown upon D, all the bevelled wheels with their corresponding pulleys remain at rest.

Fig. 120.

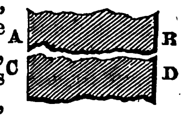


328. If the apparatus, fig. 117, is applied to those represented figs. 119 and 120, the pins P,P may be made to disconnect the bevelled wheels from the power; or to cause motion alternately in opposite directions.

329. DISADVANTAGES INCIDENT TO MACHINERY—FRICTION.—Hitherto, we have supposed the force to act without any diminution from friction, rigidity of cordage, &c.; in practice, however, these are productive of a great loss of effect. The laws which govern resisting forces are found by experiment.

330. Friction supposes motion and pressure. However smooth any surface may appear, it will, if viewed with the microscope, exhibit a great number of irregularities. When one surface, AB, fig. 121, is placed on CD, another, the inequalities of the one, to a certain extent, sink into those of the other. And, if either surface is moved, these inequalities must be rubbed off—as in the case of two pieces of chalk; or, those of the upper must slide over those of the under surface—the centre of gravity being raised. Whether the particles are violently abraded, or the centre of gravity is lifted, force is consumed. If the inequalities are to be ground off, the amount of surface must be taken into account; but if they are to be dragged over each other, the amount of surface is of but little consequence—the pressure or weight of the upper body being the chief element to be considered. When, in the latter case, we increase the surface, we diffuse, as it were, the pressure of the upper body over a greater number of particles; but the pressure on each particle will be so much less, as to leave the total amount unchanged. Hence it is, that a brick may be drawn along a table, as easily, on its broad, as on its narrow side. And a body, *just* sustained on an inclined plane, by friction, will continue to be sustained—however the weight resting on it may be increased, or diminished. For, if the tendency to slide is increased, or diminished, friction, the force which counteracts that tendency, is increased, or diminished, and in the same proportion. Hence—

FIG. 121.



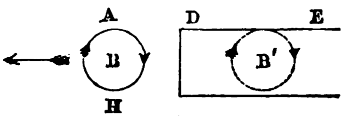
331. Broad-rimmed wheels do not render a carriage more difficult to be drawn, since they do not increase the friction. They diminish the draft, since they do not, so frequently, sink into ruts: and they are not so injurious to the road. When the surface is very adhesive, they may cause *some additional* labour to the horse; and they sometimes

encounter obstacles, which are passed over by narrow ones: —but on the whole, their advantages are greater than their disadvantages, although unfounded prejudice still prevents their more general adoption. It must be admited, however, that certain experiments made by Professor Vince, seem to indicate that friction does not increase quite as rapidly, as the pressure. Whence it would follow, that increasing the surface does, to some extent, increase the friction.

332. Coulomb showed that, when one body rests on another, the friction increases for a certain length of time. When wood is placed upon metal, it augments for *several days*.

333. *Rifling of guns*, &c.—The effect arising from the friction of a musket ball against the side of the barrel, has given rise to what is called "rifling." Experiments being made with very delicate screens; it was found that, when a ball was fired from an ordinary gun, the apertures made by it, successively, in the screens, showed it to deviate, considerably, from the direction in which it was fired. This is explained by the fact, that the ball B′, fig. 122, in passing through the barrel, rubs against one side, DE—and thus acquires a rotary motion, in the direction of the curved arrows. Hence there are unequal frictions at opposite sides of the ball, since the ve-

FIG. 122.



locities at these sides are unequal. The velocity at H, is equal to the velocity of projection, *plus* that of rotation; and, the velocity at A, to that of projection, *minus* the velocity of rotation. And the divergence of the ball from the direction of projection will be, from A towards H: since it will be more retarded, on the side opposite to that at which it rubs against the barrel—the friction of the air, against it, being greatest, where its velocity is highest. With an ordinary musket, we cannot know what side of the barrel the ball will touch: and therefore, to aim accurately with it, is impossible. The divergence is sometimes so considerable as to be attended with serious consequences.

334. To prevent these inconveniences, the ball must be

made either not to revolve at all, or to revolve in a known direction. The former is effected by making the barrel polygonal, instead of circular, the bore being larger at the breech—where the ball is introduced. In passing through the barrel, the ball is pressed violently against every side of the polygon. This prevents it from having a tendency to rotate, in any direction—and it assumes a polygonal shape.

335. A barrel is rifled, also, by forming a spiral groove round its interior. The ball, in traversing this groove, is made to rotate in a plane, nearly perpendicular to the direction of projection.

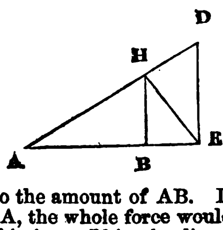
Any inconvenience, arising from the centre of gravity not being in the centre of the ball, is obviated by this plan.

336. *Friction on Planes.*—A body will just *begin* to descend on an inclined plane, when friction : pressure : : the height of the plane : its base.*

337. It follows that "the line of draft [137] should make an angle with the plane, along which the load is drawn, equal to the angle of inclination of an inclined plane of the same materials, down which a load would just *begin* to descend of its own accord."† Force will, it is true, be

* For, let the body be *just* kept at rest, at H, fig. 123. It is acted upon by three forces; friction, represented by HD; gravity, by DE; and the reaction of the plane, by EH—which is equal and opposite to HE, representing the pressure on the plane. Hence friction : pressure : : HD : EH. But, since the triangles ADE and EDH are similar, HD : EH : : DE : AE. Therefore friction : pressure : : DE : AE. And, calling the height of the plane H, and its base B, friction : pressure : : H : B.

FIG. 123.



† For, let AE, fig. 123, on an horizontal plane represent the entire friction, and EH, any force which would move the body at E. EH is resolvable into EB, opposed to friction: and BH, opposed to pressure. BH has diminished friction to the amount of AB. If the power had been in the direction, EA, the whole force would not have been expended in overcoming friction. If in the direction ED, no friction would be left—but there would be no motion along the plane.

If, therefore, the friction is represented by AB, HB will represent the corresponding pressure. And friction : pressure : : AB : HB. Hence AHB, will be the angle of inclination [336] of an in-

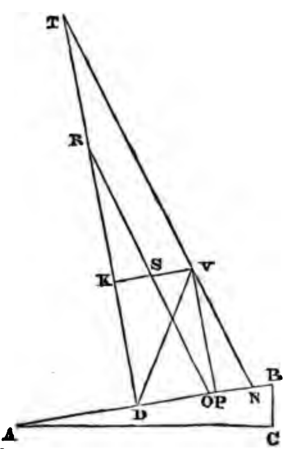
lost, on account of the direction of the power not being that [132,] in which the load is to be moved. But some, on the other hand, will be gained, from the friction being lessened, by diminishing the pressure:—and, when the angle does not exceed the proper limit, the gain is greater than the loss.

338. Pressure of Bodies in Motion.—The pressure of bodies at rest is termed *statical;* that of bodies in motion,

clined plane, down which a body would just begin to descend of itself: and, therefore, it is unchangeable. HBA, the angle made by the direction of gravity with the plane is also unchangeable. Consequently, HAB (what the sum of AHB, and HBA, wants of 180°) is also unchangeable. And AE is unchangeable; since it is the total amount of friction. Hence, EH (not supposed to be in any particular direction) must form one side of the triangle AHE, AE another side, and (since the angle HAB is unchangeable) some part of AD the remaining side.

It is evident that the power required to move the body on the plane, is least when EH, which represents it, is shortest. But it is shortest, when it is perpendicular to AD. And then HEA = AHB, because the two triangles HAB and EAH will then be similar. But AHB, is the angle of inclination of an inclined plane of the same materials, down which the body would just begin to descend of itself. Hence the power will be least, when HEA, the angle it makes with the plane, is equal to the angle of inclination of a plane of the same materials, down which a body would just begin to descend of itself.

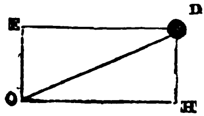
Fig. 124.



This is true, even when the plane is not horizontal. For, let AB, fig. 124, represent the pressure of a body, and also the plane on which it rests. BC will [336: note] represent the tendency down the plane—opposed to friction; and AC, the pressure on the plane—opposed to its reaction. At D, the point where the body is supposed to act, erect DR, perpendicular to AB, and = AC; draw RO, making the angle DRO equal to the angle of inclination of an inclined plane of the same materials, down which a body would just begin to descend of itself. DO will, then, be to

dynamical. Vertical pressure is diminished by motion parallel to the horizon. Let a body D, fig. 125, be carried along a horizontal plane, by a force DE, gravity being represented by DH, its tendency will be in the direction DO. It is evident that the greater the force DE, the less the relative amount of DH, and the more nearly will DO coincide with DE:—that is, the less will be the action on the plane DE. Hence, as far as the pressure is concerned, a carriage passing rapidly over a bridge, endangers the latter to a less extent than if the velocity were diminished. It is found in practice, however, that waggons, &c., produce the most effect on bridges, when in motion, the strain being increased when the velocity is augmented; and the greater strain is not in the centre, but nearer to a point of support. This apparently anomalous effect is due

FIG. 125.



RD : : friction : pressure. Therefore DO will represent the friction, corresponding to a pressure represented by RD. Let DK, be that part of the force of draft which—being perpendicular to the plane —diminishes pressure; RK, will remain the effective pressure. Through K, draw KV, parallel to AB. Since the triangles RKS, and RDO, are similar, as DO represents a friction, corresponding to a pressure RD, KS will represent a friction corresponding with the remaining pressure RK. The power must, therefore, be equal to DK and KS. But it must also include BC, the tendency down the plane—opposed to friction. Take ON=BC. Since RD (=AC) represents pressure; ON (=BC) will represent friction. Draw NT parallel to OR; and meeting DR, produced, at T. Produce KS to V. SV=ON; therefore SV will represent the tendency down the plane; and the power must include DK, KS, and SV. Draw DV, and it will represent the power. Draw VP, paralled to DK. The angle PVN is equal to the angle DRO, the angle of inclination of a plane, down which the body would just begin to descend of itself. And as VPN is a right angle; VNP, the complement of PVN is unchangeable:—so, also, is DO (the friction corresponding to the total pressure)+ON (=BC, the tendency down the plane). Consequently DN, and some part of VN, must form two sides of the triangle; and DV, the third side. Whenever, therefore, DV is shortest, the power will be least. But it is shortest, when it is perpendicular to NT. The triangles DVN and PVN, will then be similar; and the angles VDN, and PVN equal. But PVN=DRO, the angle of inclination of an inclined plane of the same materials, down which a body would just begin to descend of itself. And VDN is the angle, which the direction of the power *makes with the plane.*

to the surface of the bridge assuming the form of a curve, during the transit of the load; and the more easily the curvature is produced, the greater the deflection and strain arising from velocity.

339. The angle made by a line, representing the direction of a force, which would just begin to move a body on a plane, and a perpendicular to the plane, is called "the limiting angle of resistance." Any force, the direction of which makes a greater angle, will cause the body to move along the plane. The angle of inclination of a plane, down which a body would just begin to move of its own accord [336] is evidently greater, by an exceedingly small quantity, than the limiting angle of resistance.*

340. When the pressure is considered as unity, if the fibres are in the same direction, the friction of

Oak against oak is	0·43
Elm against elm	0·47
Fir against fir	0·56
Oak against fir	0·65

And, when the fibres are at right angles, of

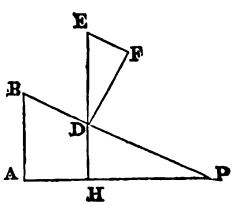
Elm against elm	0·100
Oak against fir	0·158
Fir against fir	0·167

The friction of

Brass on soft iron is	0·143
Cast-iron on cast-iron . . .	0·166
Brass on steel	0·166
Brass on cast-iron	0·166
Cast-iron on soft steel . . .	0·166
Cast-iron on wrought-iron . .	0·166
Cast-iron on hard brass . . .	0·166

* Let BP, fig. 126, be a plane down which a body, at D, would just *begin* to descend, by the force of gravity—represented by ED. The part of ED which is represented by EF [132], is just sufficient to overcome friction. If it were exactly *equal* to friction, EDF, would, according to the definition, given above, be the "limiting angle of resistance." But EDF=BPA: since their sides are respectively perpendicular.

Fig. 126.



Soft steel on soft steel . .	. 0·166
Wrought-iron on wrought-iron .	. 0·166
Tin on cast-iron . . .	. 0·2
Tin on wrought-iron . . .	. 0·2
Soft steel on wrought-iron . .	. 0·2
Brass on brass	. 0·2
Tin on tin	. 0·333

341. When the friction of wood on wood, in repose, is 0·30, in motion it is 0·20. When the friction of metal on metal, in repose, is 0·15, in motion it is 0·15.

342. When the friction on dry wood, on dry wood, is 0·30, the wood being damped with water, it is 0·65; being rubbed with tallow, it is 0·14; and being rubbed with dry soap, 0·22.

343. When the friction of metal on metal is 0·15; the metal being rubbed with olive oil, it becomes 0·06; being rubbed with lard, 0·07; with tallow 0·07; and with lard and black lead, 0·06.

344. The experiments on friction, made as yet, even by men of the greatest eminence, are but approximations to what should be the results: and the most careful experimentalists frequently differ very much in the conclusions to which they come.

The researches of Coulomb on this important subject, give rise to the following principles—

Friction, generally, varies according to the nature of the surface. In new wood, planed, it will be represented by half the pressure; in metals, by one-fourth; and in wood and metals, by one-fifth.

345. When the surfaces are worn, friction is generally, diminished, within certain limits. In wood, it is thus reduced from one-half to one-third of the pressure.

346. In woods, the friction is diminished by crossing the fibres. If, when the fibres are in the same direction, the friction is one-half the pressure, it is diminished by crossing them to one-fourth.

347. Friction is greater, between surfaces of the same kind, than between those which are different.

348. While friction is diminished, by rendering the surfaces smooth; if this smoothness is carried too far, the friction may be increased by the increased cohesion.

349. Anointing the surfaces with unctuous substances

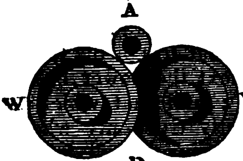
diminishes the friction: and the greater their consistence, the better. Fresh tallow lessens the friction by one-half.

350. Supposing Vince to be correct, in stating that, diminishing the surface diminishes the friction, it may be increased, on the other hand, by the groove which will be produced.

351. When the friction is caused by one body rolling on another, it is directly proportional to the pressure, and inversely to the diameter. That is, if a cylinder rolling along on a plane have its pressure doubled, its friction, also, will be doubled. But if its diameter is doubled, the friction will be only half what it was.

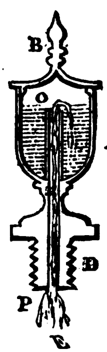
352. FRICTION ROLLERS, or *friction wheels*, are applied to diminish the friction of axles, &c., their mode of acting may be understood from fig. 127. If the axle A, instead of turning in a journal, plumbing block, &c., is made to turn on the friction wheels WW, the friction will be *nearly* as much less than it would without them, as their diameters are greater than the diameters of their axles. Since the pressure on the friction wheels is oblique, their effect is not quite as great as the ratio between the wheels and their axles. These friction wheels may be made to turn on other friction wheels—which will still further diminish the friction. If dust, &c., causes friction wheels to stop—which, not unfrequently, happens—a transverse groove is worn in their circumference, by the axle: and then they no longer revolve.

FIG. 127.



353. As a constant supply of lubricating matter is extremely important [349], in effecting a diminution of friction, various contrivances are used for the purpose. Among the best is the cup, or urn, A, fig. 128. It contains a pipe O, extending from above the surface of the oil, to below a screw D—which fits in the aperture through which the oil is to be introduced into the journal, &c.

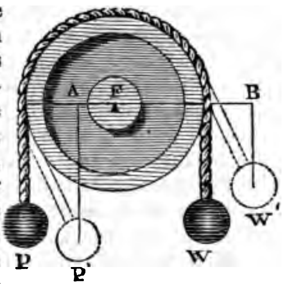
FIG. 128.



If a few threads of cotton are inserted in the tube, and allowed to hang over the top of it into the oil, they will act as a syphon; and will afford a small, but constant supply.

354. RIGIDITY OF CORDAGE.—Ropes are never quite flexible; they always, therefore, require some force to bend them:—this is so much power lost. A certain amount of the smallest thread may be kept in an horizontal position, by being held at one extremity—and hence the force required to bend it exceeds its weight. The effect of rigidity in a rope, may be understood from fig. 129. When the pulley is moved, the cord, on account of its inflexibility, tends to assume a position, approaching to that indicated by the dotted lines. The leverage will, then, be changed; for, at first, the arms, to which both power and weight are attached, were equal to the radii of the pulley; but that arm of the lever which is next the power has become AF; and that which is next the weight, BF. This is strictly true, only when the rope is quite inflexible; but it is clear, that all degrees of rigidity consume proportional quantities of power, on account of the effort required to keep the rope in the proper position—which can very seldom be completely effected.

FIG. 129.



355. Coulomb ascertained that rigidity is dependent on the way in which the rope has been manufactured, on the degree of twist, &c.; and that, as far as the drum or pulley over which it passes is concerned, the resistance, from rigidity, is inversely as the diameter.

356. The resistance to the motion of bodies in fluids—water, or air, for instance—will be shown, in hydrostatics, to vary as the squares of the velocities. When the latter are high—as when locomotives move at the rate of 40 to 50 miles per hour—it becomes very serious.

CHAPTER IV.

HYDROSTATICS.

1. Objects of the Science; and Division of the Subject.—We have considered the laws which govern the action of solid bodies; and are now to examine those which affect fluids. A fluid is a substance, the particles of which are easily moved among each other. This facility of motion arises from the excess of that repulsive power, which [mech. 12] has been attributed to heat, and which modifies the attraction of cohesion.

2. Fluids are either "perfect"—as water; or "imperfect," having a certain degree of tenacity—as the syrup of sugar. Also, they are "non-elastic"—having so little elasticity as that it may be generally overlooked—as water; or "elastic." If the latter, they are divided into those which are permanently elastic—as atmospheric air; and those—termed vapours—which are "non-permanently elastic," since they return to the fluid state, when reduced to the ordinary atmospheric temperatures. Thus steam,

at 212°, is as elastic, and as invisible as atmospheric air. But, when cooled down below that point, it returns to the condition of water; and, if it is in a state of minute division, remains suspended in the atmosphere—as cloud, mist, &c. Non-elastic fluids are often termed liquids.

3. The science which treats of the equilibrium of non-elastic fluids, is termed *hydrostatics** [mech. 2.] That which treats of non-elastic fluids in motion is called *hydrodynamics.*† And that which treats of the construction of hydrodynamic machines, *hydraulics.*‡ The mechanical properties of elastic fluids are comprehended under the science which is termed *pneumatics.*

4. Fluids are said to be non-elastic, not because they have no elasticity whatever, but because they are compressed with difficulty, and only to a small amount.

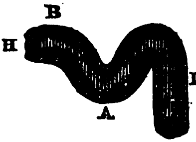
5. That some fluids are incompressible, was, for a time, considered to be placed beyond doubt, by an experiment of the Florentine Academicians, who filled a globe of gold with water, and subjected it to a pressure, which flattened it a little at the sides, so as to diminish the quantity it was capable of containing:—the water issued through the pores of the metal, but was not sensibly compressed. It was, however, incorrectly inferred that the fluid suffered *no* compression whatever; and the researches of later philosophers have shown that it is really compressible. If it is boiled—for the purpose of expelling the air which it contains—and is then placed in a tube, within the receiver of an air-pump, when the pressure of the air is diminished, its surface will be found to rise:—it was, therefore, compressed by the air. And if a bottle, containing fresh water, is, after being well corked, let down to a great depth in the sea, when it is drawn up again, the water within it will be found to have acquired a brackish taste: this shows that the enormous pressure has driven in the cork—which could not have happened unless the water inside had diminished in bulk, and allowed the sea water to enter, and mix with it.

It was ascertained by Œrsted, that water loses the 0·000046th of its bulk, for every additional pressure equal to that of the atmosphere.

* *Hudōr*, water; and *statos*, standing. *Gr.*
† *Hudōr*, and *dunamis*, force. *Gr.* ‡ *Hudōr*, and *aulos*, a pipe. *Gr.*

6. PRESSURE OF FLUIDS—HYDROSTATIC PRESSURE.—Fluids press equally in all directions. For, if any number of vessels are connected at the bottom, by tubes, all of them will be filled, when water is poured into one. The water, therefore, will be raised to, and sustained at the same height in all. Also, a vessel will empty itself, in the same time, by an aperture turned in any direction—provided it is of a given size, and at a given distance from the surface of the fluid. The use made by the ancients of aqueducts, has led many to suppose, erroneously, that they were ignorant of the property of fluids, which causes them to rise to their own level. But Pliny distinctly says, "that water ascends in a pipe to the height of the source from which it is derived."*

FIG. 130.



7. This principle is used, in what are called *traps*—which assume a variety of forms, but are all intended to prevent the passage of bad smells, from sewers, &c. Their mode of construction may be understood from fig. 130. BAD is a bent tube, of which the space A always remains filled with fluid. Gases, &c., from the sewer, cannot pass into the atmosphere, unless they descend through what is contained in A: which, since they are specifically lighter, is as impossible, as that a cork should sink, of its own accord, through water.

8. Fluids press with a force, proportional to the perpendicular height of the column above the point of pressure. Because the effect is due to the weight of the column of particles resting upon that point.

9. The great pressure, exerted at the bottom of deep seas, is evident from the fact, that wood, sunk from 4,000 to 6,000 feet, becomes perfectly soaked, and will no longer float.

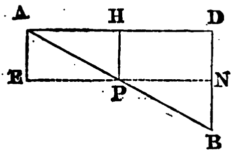
10. The fine sand of an hour-glass, seems to flow like a fluid: but it follows very different laws. Since, whatever may be its height above the aperture, or whatever may be the pressure upon its surface, the velocity with which it passes out is always the same. This may be proved, by

* Aqua in plumbo subit altitudinem exortûs sui. Plin. Nat. Hist. 31, vi. 31.

filling a tube, having a small aperture at its lower extremity, with sand:—however strongly the upper surface of the latter is pressed by a plug, &c., its escape will not be accelerated.

11. The pressure of a fluid upon a surface, in a direction perpendicular to it, is equal to the area of the surface multiplied by the depth of its centre of gravity, below the surface of the fluid. For, let AB, fig. 131, be the section of a given surface. The pressure on this line will be the sum of all the pressures derived from the columns of water, over the points which form it:—for, since [6] fluids press equally in all directions, the pressure in a direction perpendicular to the surface, is exactly the same as the downward pressure. This sum will be equal to the number of points multiplied by the mean length of the columns. But HP, the depth of P, the centre of gravity, of AB, is that mean length. For, the surface of the triangle ABD=the surface of the rectangle AEND. Hence, the sum of all the columns of water, will be the downward pressure—whether we consider them all of a mean height HP, or suppose their heights to gradually increase from 0, at A, to BD, at B.

FIG. 131.



12. If AB is not a right line, the same reasoning will still be true. And it will hold, not only with reference to the various lines of the given surface, taken separately, but also to the aggregate of the lines—or the given surface itself; the depth of the centre of gravity of which, will be the mean height of all the columns—the shortness of some, being compensated for, by the greater length of others.

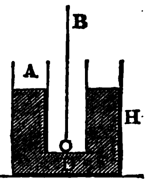
13. Hence, the pressure on the side of a cube, is half the pressure on its base. For the surfaces of the base and side are equal; but the centre of gravity of the one, is twice as deep below the surface of the fluid as that of the other. Hence, also, the pressure of the bottom of a vessel, which diminishes in size from the base upwards, may be far greater than the weight of the fluid it contains.

The centre of pressure of a fluid, is that point, at which the whole pressure may be supposed to act.

14. The upward pressure of fluids, against a surface,

may be illustrated by the apparatus, fig. 132. Let H, be a vessel containing water. Let A, be a hollow cylinder, to the ground end of which, a plate D, is accurately fitted. If the plate is kept pressed against the end of the cylinder, while the latter is immersed in the water, and the string B is then let go, not only will D not fall down—so as to allow water to enter A—but it will remain unmoved: and will, even, support any weight which —along with the plate itself—does not exceed the weight of the water that would enter A, if the plate were taken away. Whether there is water in B, or not, the pressure which would have supported it, is still in action. If water is poured into A, until the fluid is nearly at the same level inside and outside of it, the plate will fall.

Fig. 132.



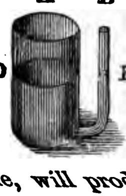
The same fact may be shown, by fitting a *thin* plate of glass, water-tight, to a cylindrical vessel open at both ends. If the cylinder is then either filled with water, or fully immersed in it, the glass plate will be broken:—this will not happen, however weak the plate may be, if the fluid is kept at the same height, inside, and outside—even though mercury is used instead of water.

15. It is easy, from what has been said, to estimate the pressure, exerted by the water in a canal, &c., against the gate of a lock, &c.

EXAMPLE.—Let the two gates of a lock be each 12 feet wide; and let the level of the water be 8 feet above their lower extremities. Taking a cubic foot of water at 1,000 oz.=63 lbs. nearly, the pressure against each gate will be $12 \times 8 \times 4 \times 63 = 24{,}192$ lbs.=10·8 tons.

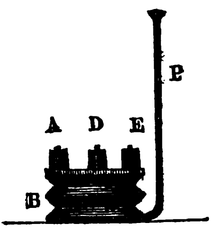
16. HYDROSTATIC PARADOX.—"An indefinitely small quantity of fluid may be made to balance one that is indefinitely large." Let the vessel A, fig. 133, and the tube B, which are connected together at their lower extremities, be filled with water to D, and E. The small quantity in B, keeps the, comparatively, large quantity, in A, in equilibrio—since, the least change in one, will produce

Fig. 133.



motion in the other. The pressure communicated by B, causes an upward pressure in A, which is capable of supporting a quantity of fluid, equal to its base multiplied by the average height [11] of the columns resting upon it. This pressure will sustain, not only the fluid in A, but any thing which may be made to supply its place. For, if we take away all the fluid which is above any horizontal stratum of particles, and replace it by a board, &c.—to receive the pressure, we may put so much weight on the board, as will be equal to that of the water which has been removed.

FIG. 134.



17. *The Hydrostatic Bellows* B, fig. 134, is constructed on this principle. It consists of two boards, connected by strong leather—something like the ordinary bellows. If water is poured into the tube, P, which is attached to it, A, D, and E will be raised—provided their weight does not exceed that of the column of water, which may be considered as replaced by the upper board.

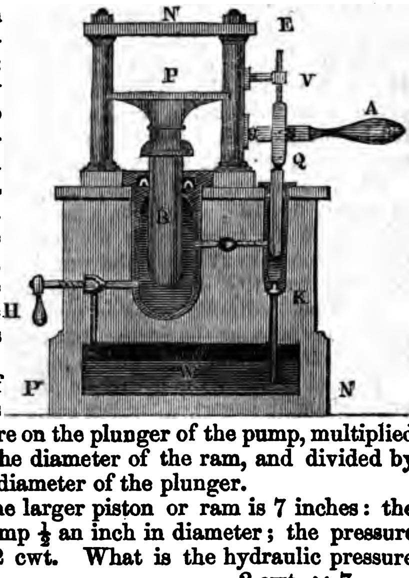
18. A person standing on the bellows, may easily lift himself, by blowing into the tube:—for it is of no consequence what the fluid is, from which the pressure is derived.

19. We may even replace the fluid, in P, by a solid piston, &c., a pressure on which will produce the same effect as would be derived from a column of fluid.

20. Bramah's Press.—The facts, which we have just explained, are used in the construction of a very powerful hydraulic press, generally called after Bramah, its first constructor. It may be understood from fig. 135:—so much of the exterior is supposed to be removed, as will be sufficient to show its internal arrangement. B, is a large piston or ram, working water-tight in a very strong vessel: and, as the tendency to leakage from the great pressure is considerable, the packing of leather, placed around it, is so contrived, that the greater the pressure the more tightly it embraces B, and the more completely it confines the water. A small pump Q, worked by the handle A, raises water from the cistern W, and forces it under B. Any thing, placed *between* P and N will, as B rises, be powerfully compressed.

The rod EQ, is kept in a perpendicular position, by a guide at V. The water flows back again into W, on turning the handle H: and B immediately descends. Two pumps are generally used with an hydraulic press: a larger to produce a rapid effect at the commencement, and a smaller to be employed when the resistance becomes greater.

FIG. 135.



21. The effect of such a machine, is equal to the pressure on the plunger of the pump, multiplied by the square of the diameter of the ram, and divided by the square of the diameter of the plunger.

EXAMPLE.—The larger piston or ram is 7 inches: the plunger of the pump $\frac{1}{2}$ an inch in diameter; the pressure on the plunger, 2 cwt. What is the hydraulic pressure upon the ram? The required pressure $=\frac{2 \text{ cwt.} \times 7}{\frac{1}{2}|^2}=392$ cwt. $=19$ tons, 12 cwt.

A pressure of 500 tons may be obtained with a good press having a ten-inch ram, with a one-inch and a two-inch pump. Friction, at the packing, destroys a very considerable amount of the power.

22. The enormous effects obtained from the hydrostatic press, have given rise to many speculations, as to its more extensive application to useful purposes. But, it must never be forgotten, that no machine can give back *more* power than it receives, [mech. 152], since none can generate power. The hydraulic press is not an exception to this law:—since, if by means of it, we can raise a great weight, we can do so, only at the expense of velocity. For, in proportion as the press is powerful, its effect will be

slow; because, just to the same extent, will the size of the force pump—compared with that of the larger vessel, which it supplies—be diminished; and through just so much the greater distance, must the hand, &c., which works the pump, travel, to produce the required result. Hence, if we are able, without such an apparatus, to lift a given weight through a certain space, in a given time; to lift by means of it 1,000 times that weight, through the same space, we shall require a period 1,000 times as long.

23. It is not, in reality, surprising, that a small quantity of water, fig. 133, should balance a very large one; since what is in the tube resists the pressure of that portion, only, which is next to it: the vessel itself, which contains the large quantity, supports the pressure of the remainder.

24. The hydraulic press is more convenient than the screw; because, as the friction between solids and fluids is *comparatively* trifling, it wastes much less force.

The principle of the hydraulic press, causes a bottle to burst when it is corked, unless some air is left above the fluid:—without this a slight blow on the cork, would generate a very great pressure within the bottle.

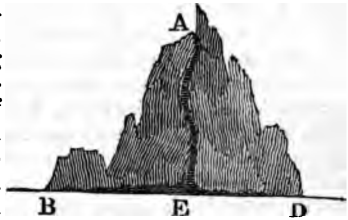
25. The hydraulic press is often used, to diminish the bulk of hay, cotton, and other light goods, for exportation. It has been proposed, also, as the means of drying the peat of our bogs, and rendering it, by its great density, capable of imparting a stronger and more permanent heat. But the expense of the apparatus, and the slowness with which it works, have hitherto prevented its general adoption. Besides, the peat being elastic, it recovers its shape to a certain extent: which prevents its remaining very dense.

26. Its principle is applied to the proof of steam boilers, &c. They are filled with water, and connected with a force pump. If any part of them is too weak, it will give way, before the safety valve—loaded more than it is intended to be, when the boiler, &c., is in use—opens and allows the water to escape. It ought, however, to be borne in mind, that the very testing of the boiler, may cause such a strain as will weaken it considerably. When it is proved with a force pump, there is no danger to the workmen, since the weak part merely opens, and water *gushes out*, the effect taking place too slowly, and the

action being exerted through too small a distance to produce an explosion:—the result would be very different, were steam pressure employed.

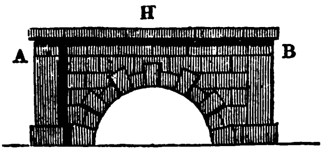
27. Some remarkable consequences follow from the property of fluids, which is at present under consideration. Thus, let BAD, fig. 136, represent the section made by a vertical plane, in a mountain containing a crevice AE—of considerable depth, but of trifling thickness, and spread out below so as to cover a large horizontal surface BD. Should this fissure be filled with water, the upward pressure may become so enormous, as to upheave vast quantities of earth, rock, &c. There is little doubt, that some very important operations of nature, are due to this cause.

FIG. 136.



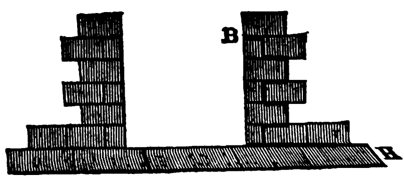
28. When a flood occurs in a river, the danger to be apprehended, is not so much the throwing down of the bridge, by the momentum of the water, as its being *blown up*, by a pressure from below:—that is, by a pressure in a direction, in which it is weak—the resistance which it exerts, arising only from the weight and cohesion of its materials. If the water reaches to AB, fig. 137—or nearly as high as the top of the battlement, the arch is pressed outwards, with a force, equal to its surface multiplied by the depth of its centre of gravity below the surface of the water [11]. The effect of such a pressure may easily be imagined.

FIG. 137.



29. If a crevice BH, fig. 138, is formed behind the wall of a canal lock,

FIG. 138.

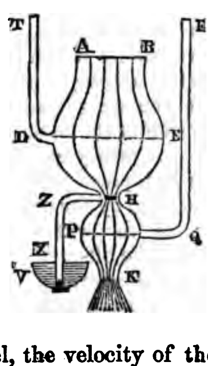


and filled with water; the latter, when the lock is emptied, exerts an outward pressure, equal to the product of the surface of that part of the wall behind which it is, and the depth of its centre of gravity, below the highest part of the fluid [11]. This may, very easily, cause the wall to be forced out.

30. If a crevice is formed under a canal bank, &c., and filled with water, it may gradually increase, to such an extent, that the outward pressure will be much greater than the weight and cohesion of the materials of the bank, can withstand. It will, therefore, be forced upwards: and the effect, to those who do not know its cause, becomes a source of great astonishment. The smallness of the quantity of water, contained in the crevice, will not be any source of security to the bank—since the least quantity, under certain circumstances, is capable of exerting any amount of pressure [16].

31. Hydrodynamic, or Hydraulic Pressure.—The pressure of fluids, as well as that of solids [mech. 338], is diminished by motion. Hence pipes occasionally burst, when they become choked, so as no longer to allow the fluid to pass. The more rapidly water flows, the less it presses against the sides of the pipe, &c. This fact may be illustrated, by the apparatus represented, fig. 139. It consists of a vessel having different horizontal sections, and tubes connected with them. The section at E being larger than that above, the velocity of the fluid passing there is, as we shall find, diminished: and its pressure being augmented by decrease of velocity, it will ascend in the tube DT, higher than the fluid in the vessel—the pressure in the lower part of DT being more than enough to counterbalance that of the atmosphere above. The section at P being smaller than that of the upper portion of the vessel, the velocity of the fluid will be greater; but its lateral pressure being less, *the fluid will not* ascend in QF so high as in the vessel.

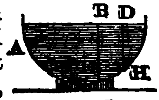
Fig. 139.



Lastly, the section at H being very small, the velocity of the fluid is comparatively very great, and its pressure is so diminished, as to have become *negative*—that is, insufficient to counterbalance the pressure of the atmosphere above: consequently, fluid will rise from the vessel V; and, if the tube ZX is not too long, it will enter the larger vessel at H and be discharged at K, the current being perceptible if the fluid in V is coloured.

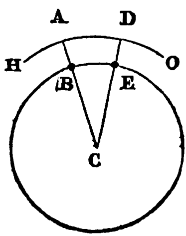
32. SURFACES OF FLUIDS.—The surface of a fluid, if at rest, is always horizontal. Otherwise two particles, E and H, fig. 140, would remain in equilibrio, although the pressure exerted by one against the other were, on account of the different heights of the columns EB, and HD, above them, very unequal. But [mech. 74] two unequal pressures cannot counterbalance each other, and produce equilibrium.

FIG. 140.



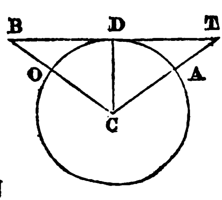
33. When the surface of a fluid is said to be horizontal, it is meant that a vertical section of it would be bounded above, not by a straight line, but by a curve parallel with the spheroidal surface of that part of the earth where it is. For the lengths of the columns of fluid over B and E, fig. 141, are to be measured on radii CA, and CD, drawn from C—supposed to be the centre of gravity of the earth: which is true, likewise, of all the columns, between AB, and DE.

FIG. 141.



34. The curved line DA, fig. 142, is the "real," but DT, a tangent to it, is the "apparent level." When there is question of short distances, it is not necessary to attend to the difference between them; but the case is otherwise, when canals, &c., of considerable length, are to be constructed. AT, the difference between the real, and the apparent level, is about 8·004 inches in one mile. And, from the properties of the circle, it is, for any

FIG. 142.



number of miles, the square of that number multiplied by 8·004 inches.*

35. This enables us to ascertain the extent of the "visible horizon"—that is, how far an observer can see, from a given height. For the number of miles will be "the square root of the quotient, of the height, in inches, divided by 8·004."†

EXAMPLE.—What distance is visible from a height of 1,760 feet? 1,760 feet=21,120 inches.

$$\sqrt{\frac{21,120}{8·004}}=\sqrt{2638·68}=51·36 \text{ miles.}$$

It is evident, that no part of the earth's surface, more distant than D, fig. 142, can be seen from T.

36. Knowing the height of an object, we can ascertain the distance from which it can be seen. For, the required number of miles, is equal to the extent of horizon visible from its summit. Because if D, fig. 142, is visible from T, T will evidently be visible from D.

EXAMPLE.—At what distance will a light, 125 feet above the level of the sea, become visible? 125 feet= 1,500 inches.

$$\sqrt{\frac{1,500}{8·004}}=13·7 \text{ miles.}$$

It is evident, that B would be visible from T, and *vice versa*. And the distance between B, and T, is equal to

* For, CD being radius, and DT tangent, $(CA+AT)^2$ (the square of the hypothenuse)$=CD^2+DT^2$ (the sum of the squares of the small sides). That is—$CA^2+2CA\times AT+AT^2=CD^2+DT^2$. But, since $AC^2=CD^2$, we have $CD^2+2CA\times AT+AT^2=CD^2+DT^2$, or $2CA\times AT+AT^2=DT^2$. That is, $(2CA+AT)\ AT=DT^2$. And (AT being very small, we may neglect it) $2CA\times AT=DT^2$. Hence, $AT=\frac{DT^2}{2CA}$. And, calling the radius R: also considering the arc DA (supposed to be very small) as coincident with its tangent, $AT=\frac{DA^2}{2R}$. 2R being about 7,916 miles, AT, for one mile, $=\frac{1}{7,916}$miles$=8·004$ inches. And, since 2R is constant, AT varies as DA^2.

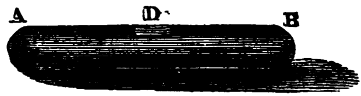
† n being the number of miles, in DA, fig. 142, AT [34]$=n^2\times 8·004$. $n^2=\frac{AT}{8·004}$. And $n=\sqrt{\frac{AT}{8·004}}$

the extent of the visible horizon at B, plus the visible horizon at T.

Refraction has not been taken into account in these calculations. But, it is found, that the distance at which an object can be seen, with refraction, is to the distance at which it could be seen without it, as 14 is to 13. When, therefore, the distance is considerable, refraction must not be neglected.

37. LEVELS depend on the fact, that the surface of a fluid, at rest, is horizontal. A "level" is an instrument, by means of which, it may be ascertained whether, or not, a given surface is parallel with the horizon. It generally consists of a glass tube, AB, fig. 143, hermetically* sealed at both ends; and filled, except a small bubble, with some fluid:—the latter is, generally, alcohol, because it moves easily, and does not freeze. If either end of the tube is higher than the other, the air in the bubble will ascend towards it. When the tube is perfectly horizontal, the bubble will rest between the extremities; and, if the tube is slightly arched upwards, it will remain exactly at the centre D.

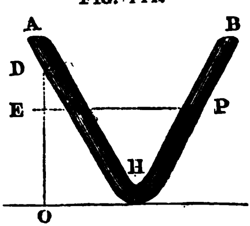
FIG. 143.



The glass tube is, very frequently, enclosed in a brass case, having an aperture which allows the bubble to become visible, when its under side rests on a truly horizontal surface.

38. If two different fluids are placed carefully in the bent tube AHB, fig. 144, so that one of them, only, shall be in the part AH, and the other, only, in the part BH, since the two parts are connected at H, DO, and EO, the respective heights of the fluids, will be inversely as the densities. For the two pressures counterbalance each other. But to produce equilibrium—if their densi-

FIG. 144.

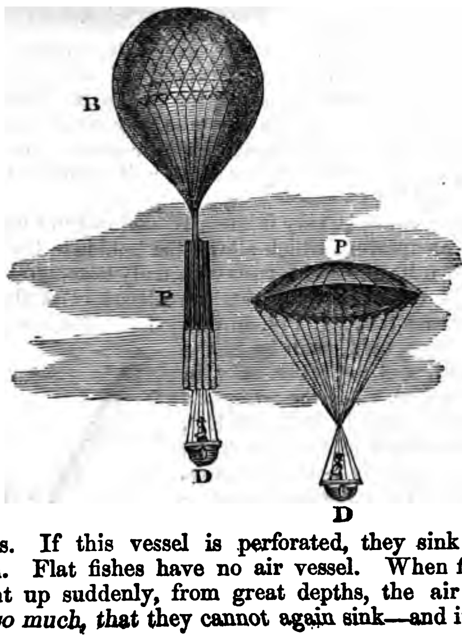


* The aperture of a tube, &c., is said to be "hermetically" sealed, when it is filled up, by fusing to its edges, enough of the substance of which the tube is made, to close it completely.

ties are unequal—the lesser density of one must be compensated for, by its greater height.

39. The ascent of a body, in a fluid of greater density than itself, arises from the upward pressure, which the weight of the body is not sufficient to overcome. For, before the body was immersed, the upward pressure supported a quantity of fluid of equal bulk, but of greater weight. Some of this pressure remains uncounteracted, and must, therefore, produce motion. But the body will not ascend, if it is placed on the bottom, in such a way as that no fluid will be under it. Fishes are nearly of the same specific gravity as the fluid in which they swim; and ascend, or descend, with facility, by altering the bulk of an air vessel contained within them, by the action of

FIG. 145.



muscles. If this vessel is perforated, they sink to the bottom. Flat fishes have no air vessel. When fish are brought up suddenly, from great depths, the air vessel *swells so much*, that they cannot again sink—and it some-

times even bursts. The air contained in the air vessels of fishes taken near the surface is nitrogen almost in a state of purity.

40. BALLOONS.—The property of fluids, just noticed, causes balloons to rise in the air. Their upward motion being due to that law, which makes a cork ascend in water. They are of two kinds, the "fire balloon" and the "gas balloon." Each consists of a bag of silk, B, fig. 145, or some other light material, covered with a netting, from which is suspended, either the car D, containing the aeronaut, or the *parachute* P. When the latter is used, the car is attached to it. The silk bag, &c., is filled with a fluid lighter than the atmosphere at the surface of the earth.

41. When it is a fire balloon, this fluid is common air, rarefied—and, therefore, rendered less dense—by a furnace placed in the car. The rarefied air ascends into the machine, and causes it to be lighter than that which surrounds it.

When it is a gas balloon, it is inflated with hydrogen, or coal gas. If the apparatus is small, the hydrogen, &c., must be freed from the water with which it is combined, by passing it through a tube containing pieces of fused chloride of calcium—a substance, which, as we shall see hereafter, has a strong tendency to unite with water. Without this precaution, the gas would be too heavy.

42. The balloon must not be quite filled with gas: since it is necessary to leave room for the expansion, consequent on the pressure around it being diminished, by its ascent into the higher regions—where the atmospheric air is more rare, and, therefore, exerts less pressure.

43. The aeronaut carries up bags filled with sand: and gradually empties them, when he desires to ascend higher:—the smallness of their particles prevents them from doing any mischief, notwithstanding the great height from which they fall. When he wishes to descend, he allows the gas to escape, by a valve at the *top:* since the air within, being lighter than that which is outside, cannot *descend:*—hence, the tube by which the balloon was inflated, may be left open without the gas escaping.

44. Balloons have been rarely used, except for experiment: sometimes, however, they have been applied by

armies, to the purpose of reconnoitring. Their great size, the difficulty of guiding, or controlling them, and the danger which attends their use, will prevent, in all probability, even at any future period, their general adoption. The fire balloon is particularly hazardous, and has, more than once, caused the destruction of life. Sometimes, gas balloons, also, have been the source of accident:—instances have occurred in which they have been burst, by the expansion of the gas; and the unavoidable [43] distance of the valve has, in some cases, rendered it unmanageable, from imperfection in the machinery.

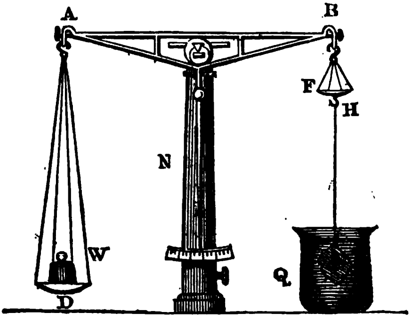
45. The *parachute* P, fig. 145, has been occasionally employed to lessen the danger, or for experiment. While attached to the balloon it remains closed: but, on being separated from it, expands, during its descent—which, at first, is extremely rapid—and then it resembles an umbrella. The great peril, attending its use, arises from its violent oscillation, and from its being likely to become entangled, in the roofs of buildings, trees, &c. Should the oscillation become such as would make it overset, it would immediately close up, and the descent would, after that, be made with frightful velocity [mech. 58]. Under ordinary circumstances, a maximum speed is obtained, soon after it has expanded—the increased resistance of the air, destroying the increase of velocity, generated by the force of gravity.

46. Specific Gravity is the weight of any body compared with that of another, considered as a standard. It is usual to compare the density of solids and fluids, with that of an equal bulk of distilled water, taken as 1, or 1,000: and of gases, with an equal bulk of atmospheric air. If the density of gases and vapours were compared with that of water, the terms of the resulting fraction would be inconveniently large.

47. We may take the specific gravity of a solid, heavier than water, by weighing it first in air, by means of the balance, fig. 146, and then ascertaining how much weight it loses, when immersed in water, contained in the vessel Q. The weight lost will be that of an equal bulk of water; and if it is divided into what the body weighed in air, the result will be the required specific gravity. Thus, if the weight of any thing in air, is three pounds, and, in water,

two pounds, the *equal* bulk of that fluid, which it displaces, weighs one pound. And $\frac{3}{1} = 3$ expresses its weight, compared with that of water —or, in other words, its specific gravity. It is three times as heavy as water, since the pressure, which supported the water it displaced, is sufficient to sustain only one-third of its weight. It is evident that the specific gravities of two bodies, are inversely as the weights they lose, when equal weights of them are immersed. Bodies are light or heavy, not on account of their *absolute* weight, but of their *specific* gravity. Thus, a pound of wool is a light, but an ounce of lead a heavy body: though the former is, actually, the heavier.

FIG. 146.



48. Since a body loses, in water, a weight, equal to that of a mass of the fluid of the same bulk, we are not to be surprised that enormous blocks of stone, &c., are rolled along by torrents:—for, when immersed in water, they become comparatively light: and a proportionably smaller force is sufficient to move them. On the other hand, a heavily laden vessel may float with safety in the sea, but may sink when it enters the fresh water of a river, in which it will become relatively heavier.

49. If the specific gravity of a body, lighter than water, is to be determined, we must add to it so much of a heavy body as will sink it. And, as the entire weight of the heavy body is not *effective*, we are to subtract the weight it loses in water from what the compound mass loses; and to divide the weight of the lighter body, in air, by the remainder. Let us suppose that the heavy body, which is added, loses one pound of its weight in water: and that the compound mass loses four pounds—the difference of the weights lost is three pounds. Let us also suppose that the

weight of the lighter body, in air, is one pound. Its specific gravity is $\frac{1}{4-1}=\frac{1}{3}$. Then $\frac{1}{3}=0{\cdot}33$, &c., will express its weight, compared with that of water. That is, water is three times as heavy: and the pressure, which supported the water, is capable of supporting three times its weight.

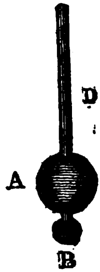
50. When a body is immersed in a fluid lighter than itself, it will displace a quantity equal to its bulk, but less than its weight: if in a fluid heavier than itself, it will displace a quantity equal to its weight, but less than its bulk.

51. A knowledge of these facts, enabled Archimedes, the famous mathematician, to detect the dishonesty of a goldsmith, to whom Hiero, king of Syracuse, had given a quantity of gold, for the manufacture of a crown. Hiero distrusted the goldsmith, and communicated his suspicions to Archimedes, that he might remove, or change them into certainty. The philosopher himself was, for some time, unable to solve the problem. But, remarking that, on entering a bath, he caused the water to overflow, a simple mode of arriving at the truth, flashed across his mind: and, delighted at the discovery, he cried out in ecstacy, "I have found it; I have found it." He saw, at once, that a certain weight of gold—the heaviest substance then known—must displace less water than the same weight of any other body. On making the experiment with the crown, furnished by the artist, he discovered, that its bulk was greater than it should be if made of pure gold. This fact once known, the amount of alloy could easily be discovered—but by methods which do not belong to our present purpose.

52. When a body is soluble in water, its specific gravity may, sometimes, be conveniently found, by immersing it in a fluid of known specific gravity, in which it is not soluble.

53. The Hydrometer, used for taking the specific gravity of fluids, is founded on the fact, that the lighter a solid is, compared with the fluid in which it is immersed, the less it will sink. It consists of a graduated stem D, fig. 147, a bulb A, and a smaller bulb B, containing mercury—which, depressing the centre of gravity of the instrument, causes it, when immersed in a fluid, to assume an *upright position*. The graduation of the stem shows the

Fig. 147.



extent to which the hydrometer sinks, in a given fluid; and, consequently, the specific gravity of the latter. When it is intended to be used with liquids that are not corrosive, it may be of brass—to render it less easily injured.

54. It has been found that, if, on account of dirt, &c., the surface of the hydrometer does not moisten freely with the fluid, it may stand in it two or three degrees higher, or lower, than it ought.

55. The Specific Gravity Bottle, also, is employed for taking the specific gravity of fluids, &c. It consists of a light glass bottle, which holds a given quantity—suppose 720 grains—of distilled water, at a certain temperature—generally 60°. If this bottle, when counterpoised, and filled with another fluid at the same temperature, weighs, for example, 550 grains; the density of that fluid must be to the density of water : : 550 : 720. And, water being unity, its specific gravity will be represented by $\frac{550}{720} = 0{\cdot}7639$.

56. We ought, if possible, to take the specific gravity of fluids, at the temperature of 60°. If we compare specific gravities, obtained at various temperatures, we must allow for the contraction, or expansion, due to the difference.

57. The specific gravity of solids, also, may be ascertained by means of the specific gravity bottle. Suppose the specific gravity of a given earth is to be found. If the bottle holds 720 grains, we place it in 360 $\left(=\frac{720}{2}\right)$ grains of water: and then so much of the earth to be examined, as, along with the distilled water, will completely fill it. Were the earth and the water of the same specific gravity, the contents of the bottle would now weigh 720 grains. But let them, instead of this, weigh 900 grains. It follows that a quantity of the earth, equal in bulk to half the interior of the bottle, weighs 540 grains; while the same bulk of water weighs but 360 grains. The density of distilled water is, therefore, to that of the earth : : 360 : 540; and the specific gravity of the earth is $\frac{540}{360} = \frac{3}{2} = 1{\cdot}5$.

58. The specific gravity of a gas may be taken, by means of a light glass globe, which is to be carefully weighed—or, to avoid the necessity of making allowance for the changes which might occur, during the course of the experiment—counterpoised, while full of air, with a similar globe. It is then to be exhausted, and the difference of its weight is to be ascertained. This will give the weight of the atmospheric air contained in it. While still empty, it is to be screwed on a receiver, containing the gas to be examined, and, being filled with the latter, is to be again weighed. The difference between its weight, when empty, and when full of the gas, will be the weight of the gas—which may be compared with what has been ascertained to be the weight of an equal bulk of common air.

59. The gas, before being weighed, must be either perfectly dried, by transmitting it through chloride of calcium; or it must be perfectly saturated with moisture, by allowing it to stand over water—and, then, the correction for the aqueous vapour it contains, may be made from the following table, which shows what portion of its total bulk is due to the vapour:—

Degrees.	Amount of aqueous vapour, in terms of the bulk.	Degrees.	Amount of aqueous vapour, in terms of the bulk.
40	0·00933	61	0·01923
41	0·00973	62	0·01980
42	0·01013	63	0·02050
43	0·01053	64	0·02120
44	0·01093	65	0·02190
45	0·01133	66	0·02260
46	0.01173	67	0·02330
47	0·01213	68	0·02406
48	0·01253	69	0·02483
49	0·01293	70	0·02566
50	0·01333	71	0·02653
51	0·01380	72	0·02740
52	0·01426	73	0·02830
53	0·01480	74	0·02923
54	0·01533	75	0·03020
55	0·01586	76	0·03120
56	0·01640	77	0·03220
57	0·01693	78	0·03323
58	0·01753	79	0·03423
59	0·01810	80	0·03533
60	0·01866		

60. The specific gravity of a gas, at any one tempera-

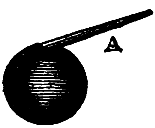
ture, may be deduced from that, at any other. For, as we shall find hereafter, it expands the $\frac{1}{192}$nd of its volume at 32° Fahrenheit, for every degree it increases in temperature.

61. The change in specific gravity, made by altering atmospheric pressure, is easily ascertained: since the volume is inversely as the pressure.

62. The specific gravity of a gaseous compound may be obtained, by adding together the specific gravities of the volumes of the component parts, and dividing the sum by the number of volumes in the compound. Thus, nitrous oxide consists of $\left.\begin{array}{r}\text{two volumes nitrogen } (2\times 0{\cdot}976)=1{\cdot}952 \\ \text{and one volume oxygen}=1{\cdot}106\end{array}\right\}=$ 3·058. But as the three volumes of the elements—being condensed during combination—form but two volumes of the compound, the specific gravity of one volume of the latter is $\frac{3{\cdot}058}{2}=1{\cdot}529$: which is the specific gravity of nitrous oxide.

63. The specific gravity of a vapour—that of alcohol, for example—at a given temperature, may be obtained by means of a light bulb of glass B, fig. 148, having a neck A, drawn out very fine in a lamp. The bulb being heated, its tube is to be immersed in the alcohol: the partial vacuum produced within it by cold, will cause the atmospheric pressure to force in some alcohol. It is then to be placed in a fluid, which boils at a higher temperature than that, to which the vapour must be raised:—chloride of zinc, the boiling point of which is very high, answers, for the purpose, in some cases; but, in others, it will be necessary to use *fusible metal*, which is made by melting together eight parts, by weight, of bismuth, three of tin, and five of lead. The bulb, and the fluid in which it is immersed, should now be raised to the required temperature—ascertained by a thermometer; and, when nothing but vapour remains in the bulb, its capillary neck is to be hermetically sealed, with the flame of a lamp urged by the blow-pipe. It is then to be cooled, and weighed:—the vapour will be condensed; but this is of no consequence, since there will be

FIG. 148.



nothing else in the interior of the bulb. The contents of the latter, in cubic inches, &c., may be found, by breaking off the fine point of the tube under the surface of mercury, and allowing the whole interior to be filled with that fluid—which is then to be poured out, and measured. If, besides the mercury, a bubble of air is perceived in the bulb, we must allow for it, since it was present, with the vapour examined.

64. In this experiment, the pressure of the air, &c., are to be taken into account [61].

65. TABLE OF SPECIFIC GRAVITIES.—

Agate,	2·590
Alum,	1·714
Amber, from	1·065 to 1·100
Ambergris, from	0·780 to 0·926
Amethyst, common,	2·750
——— Oriental,	3·391
Amianthus, from	1·000 to 2·313
Arragonite,	2·900
Asphaltum, or Mineral Pitch, from	0·905 to 1·650
Barytes, Sulphate of, from	4·000 to 4·865
——— Carbonate of, from	4·100 to 4·600
Basalt, from	2·421 to 3·000
Bees' Wax,	0·964
Beryl, Oriental,	3·549
——— Occidental,	2·723
Blood, Human,	1·053
Borax,	1·714
Butter,	0·942
Calcareous Spar, from	2·620 to 2·837
Camphor,	0·988
Caouchouc,	0·938
Cornelian, Speckled,	2·613
Chalcedony, common, from	2·600 to 2·650
Chalk, from	2·252 to 2·657
Chrysolite,	3·400
Crystalline lens of the Eye,	1·100
Coals, from	1·020 to 1·300
Copal,	1·045
Coral, Red, from	2·630 to 2·857
——— White, from	2·540 to 2·570
Corundum,	3·710
Diamond, Oriental, colourless,	3·521
——— ——— coloured, from	3·523 to 3·550
——— Brazilian,	3·444
——— ——— coloured from	3·518 to 3·556
Dolomite, from	2·540 to 2·830
Dragon's Blood (a resin),	1·204

Emerald, from	2·600 to 2·770
Euclase, from	2·900 to 3·300
Fat of Beef,	0·923
,, Hogs,	0·936
,, Mutton,	0·923
,, Veal,	0·934
Felspar, from	2·438 to 2·700
Flint, Black,	2·582
Fluor spar, from	3·094 to 3·791
Gamboge,	1·222
Garnet, precious, from	4·000 to 4·230
—— common, from	3·576 to 3·700
Glass, Crown,	2·520
—— Green,	2·642
—— Flint, from	2·760 to 3·000
—— Plate,	2·942
Granite, from	2·613 to 2·956
Gum Arabic,	1·452
Gypsum, compact, from	1·872 to 2·288
—— crystallized, from	2·311 to 3·000
Heliotrope, or Bloodstone, from	2·629 to 2·700
Honey,	1·440
Honeystone, from	1·560 to 1·666
Hornblende, common, from	3·250 to 3·830
—— basaltic, from	3·160 to 3·333
Hornstone, from	2·533 to 2·810
Hyacinth, from	4·000 to 4·780
Jasper, from	2·358 to 2·816
Jet,	1·300
Indigo,	1·009
Ironstone from Carron,	3·281
—— from Lancashire,	3·573
Isinglass,	1·111
Ivory,	1·825
Lard,	0·947
Limestone, compact, from	2·386 to 3·000
Magnesia, native, hydrate of,	2·330
—— carbonate of, from	2·220 to 2·612
Malachite, compact, from	3·572 to 3·994
Marble, Carrara,	2·716
—— white Italian,	2·707
—— black veined,	2·704
—— Parian,	2·560
Mastic,	1·074
Melanite, or Black Garnet, from	3·691 to 3·800
Mica, from	2·650 to 2·934
Milk,	1·032
Myrrh,	1·360
Naptha, from	0·700 to 0·847
Nitre,	1·900
Obsidian, from	2·348 to 2·370

Essential Oils—	
Amber,	0·868
Anise Seed,	0·986
Carraway Seed,	0·904
Cinnamon,	1·043
Cloves,	1·036
Fennel,	0·929
Lavender,	0·894
Common Mint,	0·898
Turpentine,	0·870
Wormwood,	0·907
Expressed Oils—	
Sweet Almonds,	0·932
Codfish,	0·923
Filberts,	0·916
Hempseed,	0·926
Linseed,	0·940
Olives,	0·915
Poppy Seed,	0·939
Rape Seed,	0·913
Walnuts, from	0·923 to 0·947
Whale,	0·923
Opal, precious,	2·114
—— common, from	1·958 to 2·114
Opium,	1·336
Orpiment, from	3·048 to 3·500
Pearl, Oriental, from	2·510 to 2·750
Peat, from	0·600 to 1·329
Pitchstone, from	1·970 to 2·720
Plumbago, from	1·987 to 2·400
Porcelain, from China,	2·384
———— from Sevres,	2·145
Porphyry, from	2·452 to 2·972
Pumice Stone, from	0·752 to 0·914
Quartz, from	2·624 to 3·750
Realger, from	3·225 to 3·338
Rock Crystal, from	2·581 to 2·888
Ruby, Oriental,	4·283
Sapphire, Oriental, from	4·000 to 4·200
Sardonyx, from	2·602 to 2·628
Scammony of Smyrna,	1·274
———— of Aleppo,	1·235
Schorl, from	2·922 to 3·452
Serpentine, from	2·264 to 2·999
Shale,	2·600
Silver Glance, from	5·300 to 7·208
Slate, drawing,	2·110
Smalt,	2·440
Spermaceti,	0 943
Spodumene, from	3·000 to 3·218
Stalactite, from	2·323 to 2·546

Steatite, from	2·400 to 2·665
Stone—	
Bristol, from	2·510 to 2·640
Cutler's,	2·111
Grinding,	2·142
Hard,	2·460
Paving, from	2·415 to 2·708
Portland,	2·496
Rotten,	1·981
Sugar,	1·606
Talc, from	2·080 to 3·000
Tallow,	0·941
Topaz, from	4·010 to 4·061
Tourmaline, from	3·086 to 3·362
Turquoise, from	2·500 to 3·000
Ultramarine,	2·360
Water, Distilled,	1·000
——— of Dead Sea,	1·240
Wine—	
Bordeaux,	0·993
Burgundy,	0·991
Champagne,	0·998
Constance,	1·081
Claret,	0·994
Malaga,	1·022
Moselle,	0·916
Port,	0·997
Rhenish,	0·999
Wood—	
Alder (green),	0·857
——— (dry),	0·500
Apple Tree,	0·793
Ash (green),	0·904
—— (dry),	0·644
Bay Tree,	0·822
Beech (green),	0·982
——— (dry),	0·590
Box, French,	0·912
—— Dutch,	1·328
Brazilian Red,	1·031
Campeachy,	0·913
Cedar, Wild,	0·596
——— Palest,	0·613
——— Indian,	1·315
——— American,	0·561
Cherry Tree,	0·715
Citron,	0·726
Cocoa,	1·040
Crab Tree,	0·765
Cork,	0·240
Cyprus, Spanish,	0·644

Wood—*continued.*

Ebony, American,	1·331
—— Indian,	1·209
Elder Tree,	0·695
Elm,	0·671
Filbert Tree,	0·600
Fir, Male,	0·550
—— Female,	0·498
Hazel,	0·600
Jasmin, Spanish,	0·770
Juniper,	0·556
Lemon Tree,	0·703
Lignum Vitæ,	1·333
Linden or Lime Tree,	0·604
Mastic Tree,	0·849
Mahogany,	1·063
Maple (green),	0·904
—— (dry),	0·659
Medlar,	0·944
Mulberry, Spanish,	0·897
Oak, heart of, sixty years old,	1·170
Olive Tree,	0·927
Orange Tree,	0·705
Pear Tree,	0·766
Pine (green),	0·890
—— (dry),	0·555
Plum Tree,	0·785
Pomegranate,	1·351
Poplar,	0·383
—— White, Spanish,	0·529
Quince,	0·705
Sassafras,	0·482
Vine,	1·327
Walnut,	0·681
Willow,	0·585
Yew, Dutch,	0·788
—— Spanish,	0·807
—— Knot, sixteen years old,	1·760
Woodstone, from	2·045 to 2·675
Zeolite, from	2·073 to 2·718

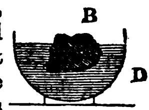
The specific gravity of the elementary bodies, and of their most important combinations, will be given, when we treat of them, in Chemistry.

66. The specific gravity of many substances is much greater than, on account of the air contained in their pores, it seems to be. That of the raspings of lime-wood was found so high as 1·13; of fir, 1·16; of oak, 1·27; and of beech, 1·29. And Rumford's experiments lead to the conclusion,

that the heavy part of all woods have a specific gravity of 1·5. If, therefore, the air it contains has been expelled by water [9] wood will sink.

67. FLOATING BODIES.—When a body floats on a fluid, the centre of gravity of the body, and of the fluid displaced, is in the same vertical line. For, whether it is the fluid displaced, or the body, that is supported by the upward pressure, the latter may be considered as concentrated at the centre of gravity. Let C, fig. 149, be the centre of gravity of the fluid; and C′ the centre of gravity of the floating body—not in the same vertical line as C. The pressure of the fluid, before it was displaced, was counterbalanced by equal and opposite pressures—those at each side of C—which must, therefore, be equal. For a similar reason, as the body is at rest in the fluid, the pressures at each side of C′, also, must be equal. But it is evident that, if half the entire pressure was exerted in supporting the water displaced, at one side of C, more or less than half, must be exerted in supporting that part of the body at the same side of C. Hence, there cannot be equal pressures at each side of C′, unless C and C′ are found in the same line, perpendicular to the horizon.

FIG. 149.



68. When a body floats on a fluid, the part out of the fluid is to the whole, inversely, as the specific gravity of the body. That is if, for instance, water has twice the specific gravity of the body, only one half of the latter will be immersed. For the more dense it is, the more of it must be immersed: since the greater must be the quantity of water displaced, that the upward pressure may support it; and *vice versa*.

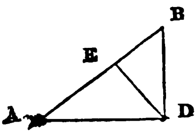
69. THE RESISTANCE OF FLUIDS arises from their tenacity, their inertia, and the friction of their particles against the solid body. The resistance of fluids to a body moving in them, varies as the square of the velocity of the body. If, for example, this velocity is increased, so that it will become three times as great, three times the number of particles of the fluid will be struck by it, in the same time; and each of them, with three times the force. The resistance will, therefore, be 9 ($=3\times3$) times as great.

and the resistance, in the one case, will be to that in the other : : $1^2 : 3^2$:—that is, as the square of velocity.

70. This reasoning holds, only when the moving body remains immersed to the same depth. But, sometimes—as in the case of swift boats on canals, steam vessels, &c.—the elevation of the body, out of the water, and its ascent up the inclined plane, formed by the wave at the bow, more than compensates for the increased velocity; so that, as is found in practice, a greater may often be maintained, with a smaller consumption of force, than a less speed. The velocity, at which the minimum power is required, depends on a variety of circumstances—the breadth of the canal, the size and build of the boat, &c.

71. Since the resistance, opposed to a body moving in a fluid, depends on its surface, and on the density of the fluid; it varies as these, conjointly. But, as far as the surface is concerned, it varies as the square of the sine of the angle, made by the surface with the direction of motion. For, let AB, fig. 150, be the section of a given surface. Its reaction is represented [mech. 76] by DE, a line perpendicular to it: but DE is the sine of the angle BAD. Also, the quantity of water, displaced by the moving body, evidently varies as BD, which is, likewise, the sine of the angle BAD. Hence, with a given surface, when both the reaction of the surface, and the quantity of water displaced by it, are variable, the resistance varies as the square of the sine (sine BAD $\times$ sine BAD) of the angle, at which the plane is inclined to the direction of motion.

FIG. 150.



The result is the same, whether it is the plane, or the fluid, that moves.

72. Another source of resistance, to bodies moving in a fluid, arises from the partial vacuum, which is produced behind them.

The sooner, and the more easily, this is filled up by the fluid, the greater the extent to which the resistance in front is counteracted. Experiment shows that, the bow and the stern of a ship being unchanged, the longer, *within certain* limits, its body is, the less the resistance.

This arises, from the velocity, and divergence of the particles pushed away by the bow, being diminished, so that, when they arrive at the stern, they fall in more easily.

73. It is found that the resistance of a sphere, is to that of a plane, having a surface equal to the surface of a great circle of the sphere : : 1090 : 2508. That the resistance of a cube, side foremost, is to that of the same cube, solid angle foremost : : 877 : 1000. Colonel Beaufoy's experiments, which were made with great care, and at considerable expense, give the following resistances, at six feet below the surface—

		1 nautical mile per hour. lbs.	2 n. miles per hour. lbs.
A triangle, whose base was equal to 1 square foot	=	1·12	64·61
Ditto, base foremost	=	2·86	194·37
A cube of 1 foot	=	3·05	202·30
An iron plane, 1 foot square	=	3·25	203·79
A round iron plane, surface equal to 1 square foot	=	3·13	205·13
A cylinder, whose base was 1 square foot, its length 1 foot	=	2·84	190·78
Same cylinder, with semiglobe on stern	=	2·34	167·97
Same cylinder, with semiglobe on head end	=	0·93	55·34
Same cylinder, with semiglobe on each end	=	0·75	46·29
A globe, whose great circle was equal to 1 square foot	=	0·88	64·87

		12 feet per second. lbs.
A cube of 12 inches, with a triangle 3 feet long at the head end, and a triangle 4 feet 6 inches at the stern	=	33·11
With a triangle 3 feet long at each end	=	33·03
With triangle at base, 4 feet 6 inches long hemicylinder at head	=	37·21
With triangle 3 feet long at base, hemicylinder at head	=	37·34
With triangle 3 feet long at head end, plane base at stern	=	48·62
The same, with hemicylinder at stern	=	42·81
The same, with hemicylinder at both ends	=	47·61

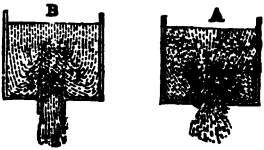
74. He found that the nearer the given body was to the surface, the more retardation was caused, in dividing the fluid. When bodies are not fully immersed, resistance will be diminished, by the absence of friction at the upper surface.

75. Spouting Fluids.—If a fluid passes along a tube of

different diameters, the velocity with which it flows, through the various portions, is inversely as their section. For the same quantity must pass through each part, in the same time; the smaller the part, therefore, the greater the rapidity, by means of which, it must compensate for that smallness.

76. If there is an orifice at the base of a vessel A, fig. 151, which is small, compared with the size of the base, the section of the fluid becomes less, after it leaves the vessel. This arises from the particles crossing, and interfering with each other, on account of the direction they take, in flowing from all parts to supply the vacuum over the aperture. The narrower part is called the *vena contracta*;* and Sir I. Newton found it to be, at a distance from the vessel, equal to the diameter of the aperture; and to bear to the aperture the ratio of 21 : 25; hence the areas are as $21^2 : 25^2$; or $1 : \sqrt{2}$, nearly.

Fig. 151.



77. The vena contracta is produced, also, when a tube is used to convey the fluid from the aperture: but Venturi remarked, that more water flowed from the bottom of a vessel B, fig. 151, having a pipe, the length of which is twice the diameter of the aperture, than from the vessel A, having an aperture without a pipe. And it is found that, while a cylindrical pipe, the length of which is four times its diameter, discharges a quantity represented by 84, a mere opening will discharge one represented by only 64. The diminution arises from the middle of the jet, alone, having all the velocity due to the height of the fluid above the aperture. If the pipe projects within the vessel, it lessens, rather than increases, the effect.

78. The velocity, at the vena contracta, is that which a body would acquire, in falling through a distance equal to the height of the fluid above the orifice—since it is derived from the action of gravity on the descending fluid. And the velocity, at the orifice, is what would be acquired by a body falling through half the height of the fluid, above the orifice.†

* Contracted vein. *Lat.*

† For as we have seen [75], the velocity at different parts of the

79. When a cylindrical, or prismatic vessel, empties itself through an orifice at the bottom, the velocity of the fluid, at the orifice, is uniformly retarded. For its velocity varies [78, note] as the square roots of the height of the columns above it—that is, as the square roots of the spaces, still to be described by the upper stratum of the fluid, in its descent:—which is exactly the way in which [mech. 62] the velocity of a body, projected upwards perpendicularly from the earth's surface, varies. And, as in the latter case, the retardation is uniform, so also must it be in the former.

80. It is evident that, if different quantities of fluids are placed in such a vessel, they will vary as the squares of the times they will require, to flow out.

81. When the vessel is cylindrical, or prismatic, the velocity with which the surface descends, is uniformly retarded. For the velocity of the upper stratum is to the velocity of the stratum at the orifice, as the surface of the latter is to the surface of the former [75]. But the ratio between the two surfaces being constant, the ratio between the two velocities, also, will be constant; and one of them will vary as the other. Hence, as the velocity at the orifice is uniformly retarded, the velocity of the descending surface will be uniformly retarded also.

82. If the vessel is a *parabolic conoid*,* the surface of the fluid will descend with a uniform velocity. For, from the nature of that solid, the horizontal strata are proportional to the square root of the corresponding altitude; so that according as the velocity is great or small, the quantity of fluid to be carried off, through the aperture

same current, is inversely as the section; hence the velocity at the orifice, is to the velocity at the vena contracta, as $1:\sqrt{2}$. But the spaces, through which the bodies fall, are as the squares of the last acquired velocities [mech. 50]. Therefore, the spaces through which the fluid should fall to acquire the velocities at the orifice, and vena contracta, respectively, are as $1^2:\sqrt{2^2}$, or as $1:2$. But the velocity, at the vena contracta, is that which would be acquired by a body, falling through a distance equal to the height of the fluid above the orifice. Hence the velocity at the orifice, is that which would be acquired by a body, falling through half that distance. It varies, therefore, as the square root of half the height of the fluid above.

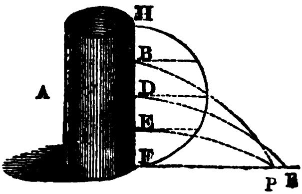
* A solid, generated by the revolution of a parabola, about its axis.

will be great, or small, also. A conoid 24 feet high, having an extreme diameter=13·28 feet, and an aperture at the bottom=0·424 inches, would form a clepsydra [mech. 258], the surface of the fluid in which, would descend uniformly: and it might be used to measure time, during 24 hours.

83. If a cylindrical, or prismatic vessel, is kept constantly full; twice as much as it can hold, at once, will run out during the time in which it would have emptied itself. For, when it is allowed to empty itself, the velocity with which the upper stratum of fluid descends, is constantly retarded; until at last it=0. But if the vessel is kept constantly full, the velocity with which the upper stratum descends, never decreases. Therefore [mech. 52] the effect in the latter, is twice what it would be in the former case.

84. To find the distance through which the fluid will spout from an orifice in the vessel A, fig. 152.—Let HF, its height, be bisected at D. With D as centre, and DH as radius, draw a semicircle. Take on the line FN, FP= twice the ordinate drawn from the points B, or E—equidistant from D—to the semicircle. FP will be the distance to which the fluid would spout, in vacuo—the vessel being kept full—from B, or E. Take FE=twice the ordinate from the point D. It would spout from D to E. In the same way, twice the ordinate from any point to the semicircle, will represent the distance, on the line FE, to which the fluid would spout, from that point. This may be proved by experiment.

FIG. 152.

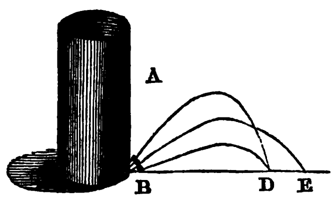


85. Thus it is found that the fluid will spout to the greatest distance, from the centre point D; and to the same distance, from any two points equally distant from D. The fluid will follow the laws of projectiles [mech. 139], and, in every case, describe a parabola.

86. If fluid in a vessel A, fig. 153, spouts from a tube at B, making some angle with the horizon, it will be thrown to the greatest distance E, when that angle is 45°; and to the same distance D, from two tubes, when the angles they

make with the horizon are equally above and below 45°. Thus, when, for example, they are 47° and 43°. This, also, may be proved by experiment.

FIG. 153.



87. MOTION OF FLUIDS IN PIPES, &c.—If a pipe attached to an aperture in the bottom of a vessel [76], is contracted in the middle, so as to form two frusta of cones, when the smaller extremities are united at the vena contracta, the discharge of fluid will remain unchanged: and the effect produced by them is greatest when, the diameter of the contracted part being five-eighths of the diameter of the aperture, it is placed, at a distance from the vessel, but little more than half the diameter of the aperture—the outer frustum being five times as long as that which is next the vessel. If the outer frustum is removed, the discharge will be diminished in the ratio of 4:3.

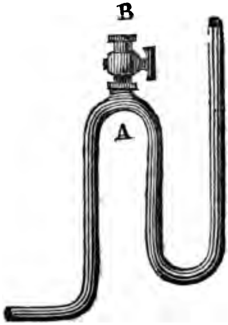
88. Causing a fluid to pass through pipes renders the speed, with which it moves, much less than it would otherwise be: and the diminution is increased, by making the velocity of the fluid greater, by roughening the interior of the pipe, &c. It is found that every length of tube amounting to fifty times its diameter, produces a waste of power equal to that which produced the general impulsion.

89. Enlargements and contractions of the pipes diminish the force of impulsion, by requiring a change in the velocity of the fluid. Sharp flexures lessen the speed, to a very considerable extent. It is found that the square of the velocity is diminished to an amount expressed by the product obtained by multiplying that square, into the square of the sine of the angle of deflection, and dividing the result by the constant number 270. While an angle of 30° would cause a loss of the 2,160th part of the force, a right angle would cause the loss to become the 540th part.

90. The air which spontaneously separates from water, collects in the higher portions of the pipes, and must be allowed to escape by valves, or other contrivances. The

ventilator, or *windpipe*, fig. 154, is often used for this purpose:—the air which collects in A, the upper portion of the curved pipe, being occasionally let off, by the cock B. Valves, made self-acting by floats, are sometimes used, instead of B.

FIG. 154.

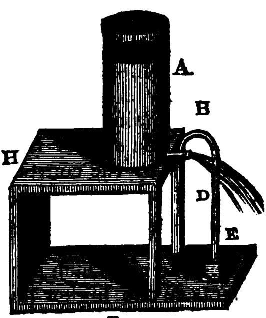


91. When the pressure within a pipe is great, it will, sometimes, be burst, by suddenly closing a cock—and thus stopping the motion [31]. This is prevented, by the use of a loaded safety-valve, similar to what is attached to the steam-boiler, and which will be explained hereafter.

92. We may ascertain the quantity of a fluid which passes through a channel, &c., by multiplying its transverse section by its velocity. The latter may be known, from the height down which it has fallen—allowance being made for the resistance arising from friction, &c.: or it may be determined, practically, by marking, with a stop-watch, the mean time required, by slices of turnip, &c.,—which have nearly the same specific gravity as the fluid—to pass through a known distance.

93. Bernouilli found that, if a small vertical pipe is attached to one that is conical and is either vertical, or horizontal, while water passes from the smaller to the larger end of the latter, fluid will be drawn up, in opposition to gravity, from a vessel into which the former descends.

FIG. 155.



94. This is a consequence of what we have already noticed [31]: and may be illustrated by the apparatus, fig. 155. A cylinder, one inch wide, and three inches long, which is fixed in the lower part of the vessel *A, has inserted* into its upper *side, at a short* distance from A,

a small arched tube BD, descending into the vessel E: and the whole rests on a stand HF. If the stream is projected, from A, with a velocity of nine feet per second, the water will rise in D, to the height of two feet. Or, if D does not exceed two feet, the column within it will mix with body of the current issuing from A; and the vessel E will be drained.

If a small opening is made in a conducting pipe, air will be drawn in, and the flow of water will not be continuous.

95. This principle causes the centre of a stream to be higher than its sides—the water being drawn from the latter, by the fluid which is in rapid motion. Venturi, availing himself of it, used the lateral draft of a mill-race, near Modena, to drain a marsh, situated at a much lower level. And we find it applied even in the animal body:—for two currents of blood, entering a large trunk, are sometimes made to exhaust a smaller vessel, lying between them.

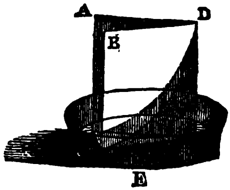
96. Capillary Attraction.—The attraction of cohesion gives to fluids a tendency to assume the spherical form: and causes several drops to unite into one—as may be exemplified, by mercury. This tendency is applied to a practical purpose, in the manufacture of small shot—which, it is evident, could be formed but very imperfectly, and not without great expenditure of time and apparatus, by casting the metal in moulds. The process employed is extremely simple. Lead is melted, and allowed to drop, in the fluid state, from the top of a high tower, through a perforated metallic plate. The attraction of cohesion causes the drops to become perfectly round; and their sphericity is permanent, since they are cooled, during their descent, and are received below, in water—which prevents their being injured by the fall. The different sizes are separated, by allowing the shot to roll down a metallic inclined plane, containing apertures, which become larger as their distance from the top increases:—the grains, that are badly formed, run off the plane, at each side.

97. An attraction is found to exist between solids and fluids. This is termed *capillary*,* because it is most

* *Capillus*, a hair. *Lat.*

strikingly illustrated by very small tubes. It has been said [32] that the surface of a fluid is horizontal:—This happens, however, only when no disturbing influence is exerted. If a solid is plunged into a fluid, the particles, next to it, will not remain at their former level. Thus when two plates of glass, A and B, fig. 156, forming a very small angle ADB, are placed vertically in the vessel E, containing water—tinted, if possible, with some colouring substance, the fluid will ascend between them; and its height will increase, as they approach each other more nearly. The curve, formed within the plates, by the surface of the fluid, is an *hyperbola* [mech. 139; note]. The increased height of the fluid, as it approaches D, is caused by the influence of one plate reaching within that of the other:—the nearer the plates are, the greater the vertical space over which that quantity of fluid, with the attraction of the plates can sustain in opposition to gravity, will be diffused—on account of its thickness having become less. A very small tube may be supposed to consist of an infinite number of plates, ranged round a central point, acting in every direction, and having a combined effect.

FIG. 156.



98. Water has been found to ascend into capillary tubes, to the height of 21 inches. It is curious that, when electrified, they will discharge water through them with great rapidity; though, otherwise, from the smallness of their bore, they would be incapable of transmitting it.

99. Mutual attraction does not exist between all solids and fluids: on the contrary, some of them repel each other —thus, glass and mercury. When this occurs, a *depression* will be found in the surface of the fluid, which has the same outline, as the *elevation* formed by attraction: but the curve will be turned in exactly the opposite direction.

100. The elevation, or depression, of the same fluid, in a tube, is inversely as the internal diameter of the tube; and has nothing to do with its thickness:—which shows that only the innermost film produces any effect. Hence,

a coating of moisture destroys the properties of a glass tube, and causes mercury to rise within it. The coating acts as a tube, and removes the mercury beyond the repulsion of the glass. If a tube have a diameter less than the twentieth of an inch, it is generally considered capillary. If its diameter is the fiftieth of an inch, water will rise in it to the height of one inch.

101. If two plates held parallel, are partially immersed in a fluid, and brought towards each other, as soon as the similarly curved surfaces of the fluid come into contact, the plates will rush together.

102. When two hollow glass balls are made to float in water, so near each other that those portions of the surface of the fluid, affected by them, will be in contact, they will unite; for the water which is raised between them, by attraction, will, in sinking down under the influence of gravity, draw them together. Also, if they are both incapable of being moistened—as two balls of wax—when they are sufficiently near, they will unite; for, a hollow, being formed between them, the pressure of the water, on the surfaces which are farthest apart, will not be counteracted by an equal pressure against those which are nearest. If one is capable, and the other incapable of being moistened, in similar circumstances they will separate: for, since the one attracts fluid, which repels the other—the water being raised by one, and depressed by the other, they cannot remain within a certain distance of each other.

103. If a drop of water is placed in the wider end of a small conical glass tube, capillary attraction will cause it to move rapidly towards the smaller extremity. The drop, when in the tube, is bounded at each end by a concave surface; but that which is at the smaller end, being the most curved, exerts the greatest attraction for the sides of the tube, the attraction being according to Laplace, inversely, as the radius of the curve terminating the column: this excess of attraction causes the drop to move in that direction.

104. Repulsion sometimes exists, between fluids. Hence, air and water cannot pass each other in a very small tube. The attraction between the glass and the fluid will prevent the latter from being driven out by the air.

105. The height to which fluid rises in a capillary tube is not, as we might at first suppose, increased by diminishing the density of the fluid; for alcohol, which is lighter than water, will not rise so high by capillary attraction. Indeed the height does not seem to have any connexion with their specific gravity:—for oil of turpentine, which is about one-seventh lighter than water, rises only one-fourth as high; and an aqueous solution of ammonia, which is one-tenth lighter than water, rises one-fifth higher. Hot and cold water rise to the same height.

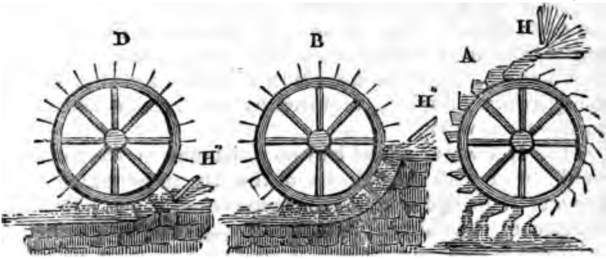
106. The insinuation of fluids between solids, at small distances from each other, is always referable to capillary attraction. It causes oil to rise in the wick of lamps, water to be absorbed by bibulous paper, &c. Some substances, such as linen, &c., are easily wetted, on account of their attraction for water being considerable in amount. And a vessel of water may be emptied, by hanging over its edge, a towel which dips into the fluid. Others are moistened with more or less difficulty, for the contrary reason: hence, silk, or wool, does not answer so well as cotton, or linen, to dry the hands, after they have been washed.

107. Some have supposed that capillary attraction causes the ascent of sap: but the effect is far greater than can be attributed to this cause. For, it has been found, that, on removing the top of a tree, and inserting a glass tube into the part which remained, the sap continued to rise through many feet of the tube.

108. Hydraulics—Vertical Water Wheels.—Water is made to drive machinery, either by its weight simply, or by its momentum. The effect is obtained, most generally, by "water wheels," which are of three kinds—the overshot, the breast, and the undershot wheel.

109. *The overshot wheel*, A, fig. 157, receives water from the sluice H, in buckets; and the pressure, at two opposite sides, being thus, rendered very unequal, a rotary motion is produced. But little effect is due to the velocity of the water. The form of this wheel should be such, that the buckets will receive the fluid, as soon, and retain *it just as long*, as it will be effective:—otherwise it will *be only a source* of pressure upon the axle.

FIG. 157.



110. *The breast wheel* is represented by B, fig. 157; its float-boards are prolongations of the radii; and the water is retained between them, by means of the masonry behind. If this is too close to the wheel, friction will be produced; if too far from it, a considerable quantity of the fluid will escape:—either would lessen the force, obtained. The fluid acts on the wheel by its weight; but the effect is increased by the velocity, which it has previously acquired.

111. *The undershot wheel*, D, fig. 157, differs from the breast wheel, by its float-boards being sometimes so arranged as to form a small angle with the radii produced: and by their being, in some instances, curved. The water acts upon this wheel, by its momentum. Undershot wheels are, often, fixed between boats, on rapid rivers. There is a great number of them in a row, across the Rhine at Mayence.

112. From the experiments of Smeaton, it appears that the dimensions, quantity of water, and height of the fall, being the same, an overshot will produce double the effect of an undershot wheel. The breast wheel, and all others which do not allow the water to descend, unless they also move, are to be considered as overshot; and they possess a power proportioned to the height through which the water descends. The effect of a breast wheel should be the same as that of an undershot wheel, whose *head of water** is equal to the difference of level between the surface of the stream and the part where it strikes the

* The "head of water" is the distance between the aperture of the sluice and the place where the fluid strikes the wheel.

wheel, added to the effect of an overshot wheel, whose height is equal to the distance from the striking point to the *tail water*.* But, as the fluid does not strike at right angles, and from other causes, the breast wheel is found, in practice—all things else being alike—to consume twice the quantity of water, required by an overshot wheel, to do the same work.

113. If a water wheel had no resistance to overcome, it would move with the velocity of the stream by which it is driven; if loaded with a resistance equal to the power of the stream, it would not move at all:—its effective velocity is between these extremes. It is found that an overshot wheel produces a maximum result, when its velocity is three feet per second.

The length and capacity of the buckets may be easily found, when the quantity of water supplied by the stream [92], is known. If the stream delivers, for instance, 18 cubic feet per second, and the buckets are to be 6 inches apart, there will be six buckets in three feet; each, therefore, if the motion is three feet per second, must contain 3 cubic feet. The quantity of water, supplied by the stream, may be determined, very conveniently, by "extracting the square root of the depth, in feet, from the surface of the water to the centre of the orifice of discharge, and multiplying the result by 5·4:—the product will be the velocity, in feet, per second; and this, multiplied by the area of the orifice, in feet, will give the number of cubic feet which flow through, in a second."

114. An undershot wheel produces its maximum effect, when its circumference moves with, between one-half and one-third of the velocity of the stream.

115. The part of the wheel from which the power is obtained, is a very important consideration. To take it from either the axis, or circumference, would be incorrect. There is only one point of a striking or revolving body, where its action may be supposed to be concentrated, and at which, if a force sufficient to cause the body to stop, is applied, it will without any strain, at once assume a state of rest. In striking bodies it is called the *centre of per-*

* The "tail water" is that which is discharged from the bottom of the wheel, after having produced its effect.

cussion: and when they revolve round a fixed point, it coincides with the *centre of oscillation* [mech. 264]: but when they move parallel to themselves, with the *centre of gravity* [mech. 94]. It is well known, that a stick of uniform density and thickness, will give the most efficient stroke at a point two-thirds distant from the extremity about which it revolves. If it increases in thickness towards the end which is farthest from the centre of motion, its centre of percussion will approach nearer to that extremity. The same laws apply to all wheels, from which power is taken. As the rim of the water wheel is, comparatively, very heavy—particularly that of the overshot, which contains water in the buckets upon one side—the point at which the greatest effect will be produced, is very near to it. In practice, it is usual to consider its distance from the rim, as equal to one-fourth of the radius. Placing cogs on one of the rings of the water wheel, or using a driving wheel, equal to it in size, is very injudicious.

116. If the power is taken from a point too near the centre of motion, the outside of the wheel will have a tendency to move with greater velocity than its central part—which may cause the shaft or axle to be broken.

117. To prevent unequal strain, the power should be taken, also, from a point opposite to where the water produces its greatest effect.

118. The power of an overshot wheel is to the effect produced : : 3 : 2. But the power of an undershot wheel is to its effect : : 3 : 1 :—when, however, curved floats are used, the effect is two-thirds, or even three-fourths of the power.

To ascertain the "horse-power" of any wheel, we have only to divide the number of pounds of *actual effect*, per minute, by 33,000: this being, as we shall find, what is considered to be a horse power, and is taken as the standard of comparison.

EXAMPLE.—A stream supplies 45 cubic feet of water per second, to an overshot wheel moving at the rate of 3 feet per second. What is its power?

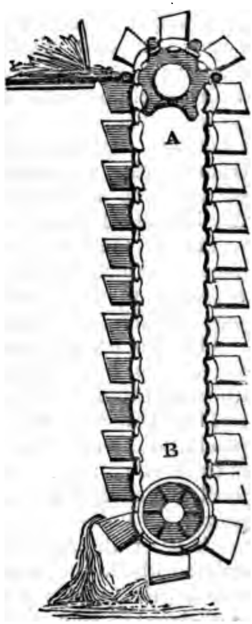
The effect being equal to two-thirds of the power, the supply may be considered as 30 cubic feet per second. And as a cubic foot of water weighs about 63 lbs., the effect is

$30 \times 63 = 1,890$ lbs., falling 3 feet per second—and, therefore, capable of raising 1,890 lbs. 3 feet per second: or $1,890 \times 3 = 5,670$ lbs. 1 foot per second; and $5,670 \times 60 = 340,200$ lbs. 1 foot per minute.

But $340,200 \div 33,000 = 10\frac{1}{3}$ nearly, the horse power of the given wheel.

119. It is important that the "tail water" should escape with as much facility as possible, otherwise the resistance, offered by it to the motion of the wheel, will consume some of the power. The principle already mentioned [93, &c.,] is used to effect this object. Two drains, or tunnels, are made through the masonry, at each side of the wheel, so as to permit some of the water from above, to flow down in front of the wheel. The current thus produced, will [95] carry off the water which is injurious; and no inconvenience occurs, as *tailing* happens only when water is plenty. The drains may be closed, or regulated by sluices.

Fig. 158.

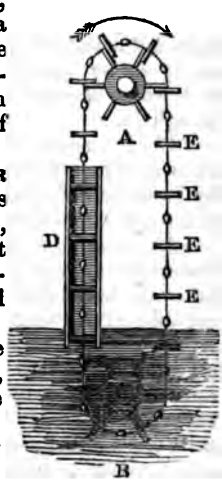


120. *Chain Wheels* are sometimes used, when the fall is high. They consist of two wheels, A and B, fig. 158, over which passes a chain of buckets. The power is supposed, in the figure, to be taken from A, and B is intended as a guide: but the arrangement may be reversed, when necessary. This machine is found to be extremely inefficient, on account of the loss of power by friction, &c.; and the wear and tear, also, is very considerable.

121. *The Chain Pump* is somewhat similar, in construction, to the chain wheel:—it is used in ships, &c., and consists of two wheels, A and B, fig. 159, and a series of *plates*, connected together by iron work. B guides: but

A both moves and guides the plates, which pass up, on one side, through a barrel D, that fits them with tolerable accuracy. This pump has the advantage of not being easily choked with sand, &c., which would destroy one of the ordinary construction.

FIG. 159.

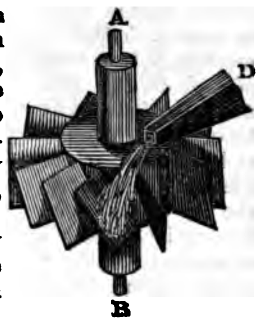


122. HORIZONTAL WATER WHEELS, OR TURBINES.—The wheels which we have described, are vertical, and their axles horizontal: but what are now generally designated "turbines," are horizontal, having vertical axles.

123. With horizontal wheels, the force is derived from impact, pressure, or reaction—but never from the weight of the water.

124. *Impact Wheels* are very simple, but not very efficient. Rectangular floats, fig. 160, making with the horizon an angle of between 50°, and 70°, are fixed to a wheel, which turns on the axis AB; and water is thrown upon them, nearly at right angles, by the trough D. Such a machine is used, when the fall is from 10 to 20 feet, if a great number of revolutions is required, and simplicity of construction is more important, than economy of power.

FIG. 160.

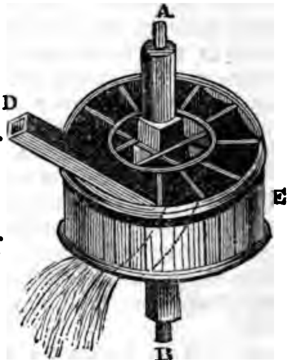


125. The effect is increased by forming the floats into the shape of spoons, or surrounding them with a rim.

126. *Impact and Reaction Wheels, &c.*—When the floats are lengthened and curved—so that the water leaves them in nearly an horizontal direction, their power is augmented by the quantity of foree derived from reaction. This construction is exemplified in *Borda's turbine*, fig. 161, the floats of which, are formed in the way represented

by the dotted lines, and are fixed to a rim attached to the axle AB: the whole revolves freely in an external case E, and water is supplied by the trough D.

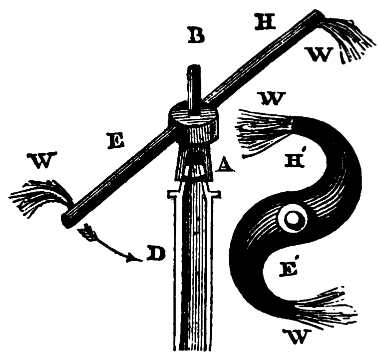
FIG. 161.



127. *Pressure Wheels.*—If the water acts without impact, by pressure only, the machine is termed a "pressure wheel."

128. *Reaction Wheels.*—If water flows from D, fig. 162, into the horizontal tube EH, capable of turning round, at A, as long as EH is closed on all sides, there will be no motion. But if an aperture is formed at one side of E, and another at the opposite side of H, the water will escape: and, the pressure on the portions exactly opposite to these apertures being now uncounteracted, EH will revolve. This rotary motion may be communicated to machinery, by means of a spindle B. The *theoretical* effect will be obtained, by multiplying together the area of the apertures, the pressure per square inch—which depends on the height of the column above the centres of the orifices, and the velocity of the arms at the apertures. But, the result is greatly diminished by the fulcrum, against which the water acts, being movable—a portion of the force being expended, in producing the velocity with which the escaping fluid moves in the opposite direction. The force obtained is evidently proportional to the water used: for the large

FIG. 162.

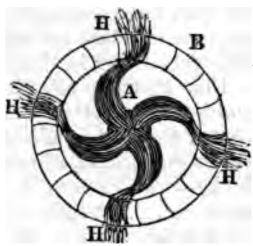


the openings, and the greater the pressure, the more water will escape.

129. In the older forms of this apparatus, termed *Barker's Mill*, there was a great waste of power, on account of the water being let in *above* through a vertical tube, occupying the same position as B, fig. 162, and of the same height as the column of fluid, whence the pressure was derived;—great force was necessarily expended, in causing this column to revolve along with the horizontal arms. But in the form represented, the water is let in *underneath*, and the apparatus revolves water-tight, at A, by means of a conical joint—the front of which, in the figure, is supposed to be removed, that the interior may be visible. This is but little affected by wear, since the weight above it is, almost entirely supported by the upward pressure of the water, acting immediately under B.

130. A greater effect is obtained from the fluid, if the arms are curved, as represented by H′E′, fig. 162:—since it *gradually* imparts motion, by pressure against the curved sides: and has but little velocity when it leaves the apertures.

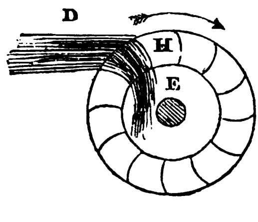
FIG. 163.



131. The force, however, which still remains may be employed to drive a second wheel B, fig. 163, which, it is evident revolves, in a direction opposite to that of the arms; but the effects may be combined, by reversing the motion of either—with some of the contrivances, which we have noticed, in mechanics.

132. *Tangential Turbines* are those, in which the tangential force of the water is used to produce the effect. Their mode of action may be understood, from "*Poncelet's turbine*," fig. 164. It is nothing more than an undershot wheel, with curved floats [111], and turned on its side. The water enters through D,

FIG. 164.



and running along the curved channels, is discharged into the interior E. The tangential force, which it has on entering, tends to carry it faster than the parts of the wheel nearer the centre; and, having a higher velocity than these parts, it increases the rapidity with which they revolve.

133. Vertical water wheels can scarcely be used, when the fall exceeds 60 feet; turbines may be employed when it is so much as 500 feet. But the higher the fall the less, in proportion, the effect of the turbine; and the resistance increases, as the square of the velocity [88, &c.] When the fall is between 20 and 40 feet, vertical wheels are more effective than turbines: when it is between 10 and 20, they are on a par; when it is lower than 10, the turbine has the advantage. Turbines are greatly affected by a change in the supply of water. The better kinds of turbine, require considerable skill in their construction; but, on the whole, their expense is about equal to that of the vertical wheel—circumstances being the same.

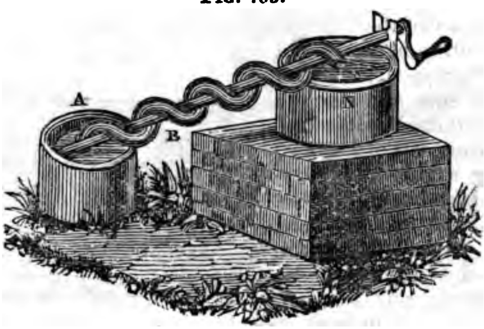
134. *Water-pressure Engines* will be understood, when we shall have treated of the steam engine; since these two kinds of machine are very like, in construction—the chief difference being in the moving power.

135. PADDLE WHEELS OF STEAM VESSELS.—A great number of contrivances have been, at various times, invented for the propulsion of vessels by steam, &c.; among others, apparatus, resembling the fins of fishes—the feet of ducks—water drawn in at the bow, and forced out at the stern, &c. But those which have been found most successful, are the "paddle wheel," and the "screw." The former is very similar in shape and action to an undershot water-wheel: but there is this difference, that with the one, the wheel drives the machinery, while with the other, the machinery drives the wheel. The great imperfection of paddles is, that when they enter, and when they leave the water, power is wasted—in the former case, by *depressing*, and, in the latter, by *lifting* the fluid. This is called the *back water;* and many methods have been suggested to remove or, at least, to lessen the evil arising from it. The chief of these, have had for their object, to make the *paddles feather*—that is, to make them enter and leave the

water perpendicularly—which is effected by the rower, when he "feathers" his oar. But complication of construction, or error in principle, has caused many of these contrivances to be abandoned: and the simplest form of paddle wheel, is that which is still, almost universally, adopted.

136. The depression, and lifting of the water are found to produce another serious inconvenience—a destructive and unpleasant vibration of the machinery and vessel, which is often much increased, by the ebullition of the water in the boiler. What is due to the former cause, is diminished by breaking the paddles, longitudinally, into small portions, arranged parallel with each other—but so as to lie in a curve. The effect is, then, neither so injurious, nor so disagreeable, since it is divided into smaller portions, and is rendered more continuous.

FIG. 165.



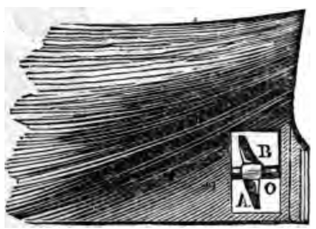
137. THE SCREW OF ARCHIMEDES, is said to have been invented, by that celebrated philosopher, about 200 years, before Christ, for the purpose of draining the land of Egypt: others, however, ascribe it to the Egyptians. It consists of a hollow spiral tube, B, fig. 165, wrapped round an axis, along with which it is turned by means of a handle. Sometimes it is moved by a small paddle wheel, attached to its lower extremity. As each part of the screw, during its revolution, changes from a lower to a higher position, the fluid within it falls backwards, but, at the same time, is

lifted by the under surface of the interior, so that it gradually ascends from A, until at length it flows into N.

138. A machine, somewhat analogous, consists of a wheel, the spokes of which are hollow, and curved. Water is taken in at the circumference, and delivered at the centre: and the machine may be put in motion by float-boards, fixed on the side of its rim, &c.

139. Screw Paddles.—The various inconveniences attending the use of paddle wheels, have caused them to be more or less superseded, by the "screw paddle" which, from a distant resemblance to an apparatus already described [137], has been termed by some the "Archimedean Screw." We find, by the Transactions of the American Philosophical Society, that it was used at New York, by Bushnell of Connecticut, so early as the year 1776—being intended to propel a submarine boat, contrived for the purpose of fixing to the bottoms of ships, an explosive preparation, by which they were to be blown up. It consists of a variable number of paddles, B, A, &c., fig. 166, constituting portions of a plane wrapped round an axis, in such a manner as to be attached by its edge, and form parts of a screw, having a thin but very deep thread. The axis to which the paddles are fixed, passes through a water-tight aperture, into the vessel; and a rapid motion is communicated to it, by means of a steam engine—generally in conjunction with a powerful wheel and pinion, which increase the velocity of rotation. The screw is most usually fixed in an aperture in the dead wood, exactly in front of the rudder; and is sometimes so arranged, as that it may be lifted up, when not in use.

Fig. 166.

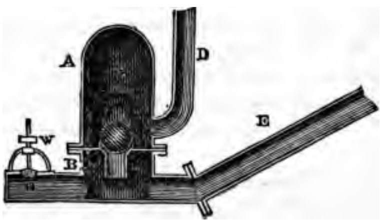


140. Much of the power applied to the screw is wasted, since the reaction of the planes of its paddles, is in a direction very different from that of the vessel. To produce any effect, it must move with so considerable a velocity, that *obtaining* the proper speed, by means of the ordinary steam

engine, is attended with difficulty and inconvenience. The screw causes little, or no disturbance in the water; it does not affect the symmetry of the vessel: and it is always submerged—which is not the case with paddle wheels, one or the other of them being, in rough weather, often raised completely out of the fluid: and it is, in many respects so convenient, that it would be fortunate if the disadvantages, which in practice are still found more or less to attend its use, were removed—so as to cause its universal adoption.

141. THE HYDRAULIC RAM.—We have said [91] that, when the flow of water in pipes is suddenly checked, a considerable force is generated. This property of fluids, which is sometimes attended with inconvenient results, has been usefully applied, in what is called the "hydraulic ram," fig. 167; a valve H, opening downwards, allows the water to escape, and thus a current is produced in the inclined pipe E, in which, the fluid acquires, by this means, a momentum sufficiently great to close H. The motion being thus suddenly checked, a pressure is generated, sufficient to lift the valve within the vessel A, and ultimately to force the water up through the pipe D. The valve in A is, most conveniently, made in the form of a ball, which is prevented from rising too high by a metallic bridle. The stoppage of the water diminishes its momentum, and it becomes incapable of any longer supporting the valve H—which therefore falls, and allows the fluid to escape: and the water descending through E, again acquires a momentum which closes H, and forces more of it into A. Thus, the action is continued, as long as the proper supply is maintained.

FIG. 167.



142. A very small fall through E, will raise a column of considerable elevation in D: but a large quantity of water escapes at H. If the pipe E is not sufficiently long,

water will be thrown back into the reservoir, instead of into A. The stream should not be variable, since the weight W must be adjusted to it.

143. The air in the upper part of vessel A is gradually taken up by the fluid, and carried away; but a fresh quantity is admitted by a valve B—above which a small vacuum is formed at each stroke.

CHAPTER V.

PNEUMATICS.

Objects of the Science, 1.—Properties of the Air, 2.—The Diving Bell, 8.—The Condenser, 10.—The Air Gun, &c., 14.—The Air Pump, 19.—Pressure of the Air, 28.—The Barometer, 30.—Pumps, 44.—Syphons, 53.—Sound, 56.—Conduction, &c., of Sound, 57.—Musical Sounds, 69.—The Gamut, 70.—Sympathy, 77.—Temperament, 83.—Tuning of Pipes, Strings, &c., 88.—Reflection of Sound, 95.—Concentration of Sound, 97.—Interference of Sound, 98.—Buildings for Public Speaking, 99.—Ventriloquism, 103.—The Wind, 104.—Anemometers, 107.

1. Objects of the Science.—"Pneumatics"* treats of the mechanical properties of permanently elastic fluids of which atmospheric air is considered to be the type, just as water is considered the type, or representative, of non-elastic fluids—so far as their mechanical properties are concerned. Although the mechanical properties of all non-elastic fluids, or all elastic fluids, are the same, their chemical properties are, as we shall find, extremely different.

2. Properties of the Air.—It is evident that air is a material substance, as it possesses those qualities which characterize matter. It comes, even directly, under the cognizance of the senses; for, though, like water, and many other fluids, it is invisible, when in small quantities, the case is very different when its mass is considerable—since it is then blue, and imparts that colour to the objects which are seen through it.

* *Pneuma*, air. *Gr.*

3. The air is *impenetrable;* for, though we may diminish the space it occupies, we can no more annihilate it, than if it were one of the most unyielding substances.

4. It has *extension* :—since, not less than solid matter, it occupies some portion of space. And it possesses *figure* :—since, not being infinite, it must assume some definite shape.

5. It has *inertia* :—for it cannot be moved, when at rest, nor stopped, when in motion, without the expenditure of force. This truth is established by abundance of facts:—by the difficulty of moving bodies rapidly through the air: or of making large organ pipes speak: and by the force necessary to resist the wind, when in motion, &c.

6. It is *elastic* :—since it is capable of being either compressed, or rarefied. The particles of elastic fluids do not seem to exercise any mutual attraction, but the contrary: for they are brought near each other only by some force—as that of gravity, &c., and the smaller the distance which separates them, the greater the difficulty of overcoming their mutual repulsion.

7. The air being, like other material substances, affected by gravitation, has *weight.*

We shall now point out how the most important of these properties are illustrated, and what apparatus is due to a knowledge of them.

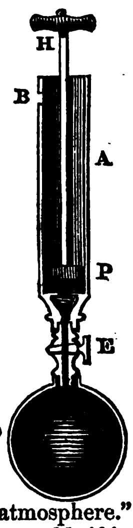
8. The Diving Bell.—The impenetrability of air is exhibited by the "diving bell," the principle of which may be shown in a familiar way, by inverting a wine glass in water. As the glass is immersed in the fluid, the bulk of the air in the upper part of it, is diminished; but, to whatever depth it may be sunk—and, consequently, to whatever pressure the air within it may be exposed, there will still be a portion of the vessel, into which the water will not enter.

9. The diving bell is a strong iron box, of any shape, open at the bottom, and having thick pieces of glass fixed, in various places, for the admission of light. The water which, as the bell descends, enters on account of the compression of the air within, is driven out by an additional quantity of air forced in from above. To enable the workmen to remain in the bell, fresh air must be constantly

pumped down: the vitiated air, being warmer, ascends, and escapes through an aperture in the upper part, into which the water cannot pass—on account of the pressure from within. The chief inconvenience experienced by persons descending in the diving bell, arises from the very condensed state of the air, which—particularly at first—causes a painful sensation in the ears, &c.: and they must not be stopped with cotton, &c., as it would be forced into the head. The workmen below communicate with those above by signals.

10. THE CONDENSER.—The compressibility of the air may be proved by the condenser, fig. 168. It consists of a cylinder A, in which a piston P is moved air-tight, by the handle H. When P is forced down, the air under it, being condensed, opens the valve in the lower part of A, and rushes into the vessel D. When P is drawn past the aperture B—forming a communication with the atmosphere—air rushes into A, and is, in the same way as before, driven down into D. This compression goes on, as long as the force, applied at H, is sufficient to open the valve in D, in opposition to the force exerted against it, by the elasticity of the compressed air in the vessel; or until the latter bursts.

FIG. 168.

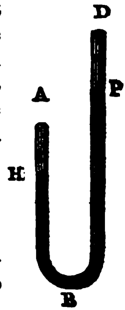


11. The pressure on the inner surface of D, is inversely as the space occupied by the air within it. When it contains air of the same density as the external atmosphere, the pressure is said to be that of "one atmosphere." When it contains three times as much air as it would, if in communication with the atmosphere, the air within it occupies only one-third of its ordinary space; and its pressure is three times as great—or that of "three atmospheres," &c.: two only of these, however, tend to burst the vessel, one of them being, as we shall see, counteracted by the pressure of the air without.

12. We may prove that the air occupies a space inversely proportioned to the force which compresses it,

by means of the bent glass tube ABD, fig. 169, hermetically sealed at A. The dark part represents mercury, which, pressing on the air in HA, diminishes its volume: and it will be found, on making the experiment, that doubling the pressure—taking that of the atmosphere into account [11]—will diminish the space HA, to one-half; tripling the pressure, will diminish it to one-third: and so on. This law—announced by *Mariotte*—does not, however, hold in extreme cases.

FIG. 169.



13. Some gases become fluid under considerable pressure. The following require to liquefy them:—

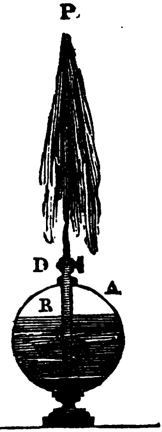
Gases.	Pressure in Atmospheres.
Nitrous oxide, . . .	44
Carbonic acid, . . .	36
Hydrochloric acid, . .	24
Sulphuretted hydrogen, . .	15
Ammonia, . . .	5
Cyanogen, . . .	3
Sulphurous acid, . . .	2

14. THE AIR GUN, &c.—In this instrument, the elasticity of condensed air, is used for the propulsion of a ball. Air is condensed by the syringe, fig. 168, into a small, but strong spherical vessel, which is screwed to the gun. On drawing the trigger, a portion of the air, liberated by means of a valve, rushes along the barrel, and drives the ball before it, with a force dependent on the amount of condensation. The velocity with which a body is projected being as the square root of the force, if the force of gunpowder is four times as great as that of compressed air, it generates twice as high a velocity. The force of gunpowder has been estimated at 1,000 atmospheres:—to produce, therefore, the same effect by means of air, it must be condensed, so as to occupy only the one-thousandth part of the space it naturally fills. But—the capacity of the receiver, attached to the air gun being large, compared with that of the barrel—the density of the air is but little altered by the discharge; consequently, the ball is driven *the whole length* of the barrel, with nearly the same force

—which is not the case when gunpowder is used. Hence, it is found that air, having the pressure of only ten atmospheres, will produce a very considerable effect.

15. *The Condensed Air Fountain*, fig. 170, consists of a strong copper vessel A, having a tube—which passes nearly to the bottom of it—inserted air-tight into its neck. A portion of the vessel being filled with water, a large quantity of air is to be forced into the space R, by the condenser [10]:—being lighter than the water, it will ascend through that fluid, and occupy the higher portion of the vessel. The stop-cock D being closed, and the condenser removed, a variety of jets may be screwed on; and, when the cock is opened, the air, pressing on the surface of the water, will force it violently up through the pipe and jets.

FIG. 170.



16. An air-vessel, acting upon this principle, is attached to hydraulic machines, whenever an uninterrupted stream is to be obtained from an intermitting supply:—the size of the aperture, through which the constant stream is to issue, is made sufficiently small: and the pressure required, is supplied by condensation of the air. An air-vessel is used with the hydraulic ram [hyd. 141], &c.

17. *Heros' Fountain*, also may be employed to illustrate the effect of condensed air. In its simplest form, it consists of a bottle B, fig. 171, containing water, into which the long funnel F, dips: a small bent tube E, forms a communication between B, and another bottle A, which likewise contains water—into which the tube D, having a small opening at its upper end, dips. When water is poured into F, it forces the air contained in the upper portion of B, through the tube E, into A; and this air, pressing on the surface of the water, forces it, in a jet, through D.

18. *The Hungarian Machine* is constructed on the same principle as Heros' fountain. It derives its name from having been used to drain a mine, at Chemnitz, in

FIG. 171.

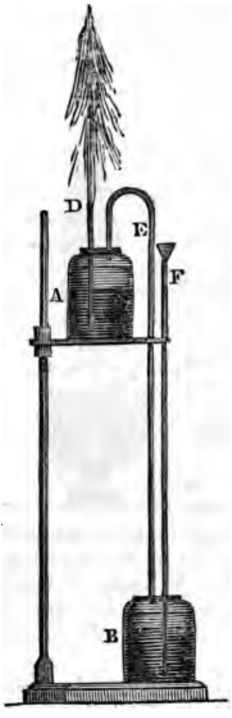
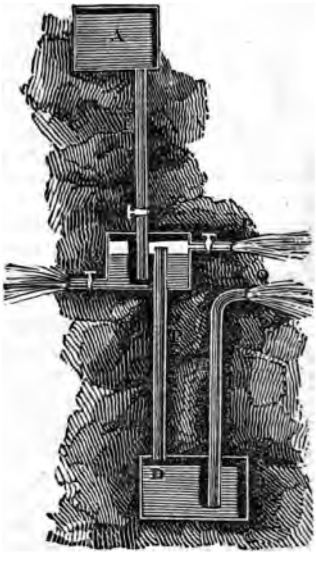


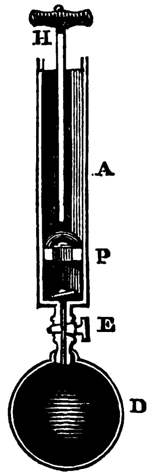
FIG. 172.



Hungary. Three reservoirs, A, B, and D, fig. 172, are connected by pipes: the reservoir D, communicates with the atmosphere, by means of H. When water is made to flow from A into B, the air, with which the latter was previously filled, is driven down through the pipe P, and pressing on the surface of the fluid in D, forces it to ascend in the pipe H, and flow out at Q. On opening the cock, for the purpose of removing the water from B, air and water rush out through it with great violence: and the sudden expansion—for a reason to be explained hereafter—causes *a cold, sufficient* to change the water into lumps of ice;

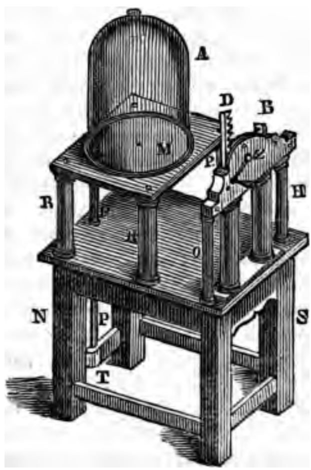
which issue out with so great force as, sometimes, to perforate bodies, like pistol bullets.

FIG. 173.



19. THE AIR PUMP, and a variety of experiments which it enables us to make, prove that the air expands, when the pressure is removed. It was invented by Otto Guericke, of Magdeburgh, about the year 1654, and was improved by Boyle. In its simplest form, it is an exhausting syringe A, fig. 173, which consists of a piston P, moving air-tight in the cylinder A, by means of the handle H. When P is drawn up, the air under it expands, and its pressure is proportionally diminished, so that it is no longer able to counteract the pressure of the air in D—which, therefore, opens the valve in the lower part of A, and rushes into the latter. When P is pressed down, the air which rushed out of D, being condensed, acquires sufficient elasticity to close the valve in the cylinder, and, after a while, to open that which is in the piston, so as to rush into the atmosphere. In this way the air is drawn out of D, until what remains within it is not elastic enough to raise the valve in A.

FIG. 174.

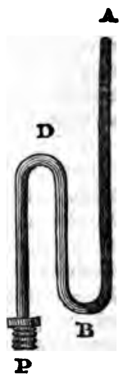


20. Fig. 174 represents a more perfect form of a pump. It consists of two cylinders, or barrels—similar in construction to that which is represented, fig. 173—worked by racks, and a pinion which is moved backwards and forwards by a handle. A ground brass plate, is fixed to a stand, which rests on

pillars RR, and an aperture, in the centre of it, forms a communication between the receiver A, placed upon it, and the exhausting cylinders—by means of a small pipe, containing a stop-cock. The pillars O, and H, bind the various parts together, and the entire is securely attached to a strong frame NS. The valves in the cylinders, and pistons, consist merely of small circular apertures, over which are placed narrow strips of oiled silk, secured only at their extremities—that the air may pass freely, at each side of them, when they are raised by its elastic force. The piston being drawn up in one barrel, it is depressed in the other: and the degree of exhaustion within A is indicated by the *barometer gauge* P, the cup of mercury belonging to which, is seen at T. We shall explain this gauge presently.

21. Many improvements have been made, in the details of the air-pump, since it was first invented. And a number of contrivances have been suggested, for rendering the action of the valves more delicate—such as lifting them mechanically, and without any aid from the elasticity of the air beneath them, &c. Most probably, the best of the methods proposed is to relieve them of some pressure, by means of a subsidiary air pump.

FIG. 175.



22. *The Syphon Gauge* is sometimes used, to indicate the exhaustion in the receiver. It consists of a bent glass tube, fig. 175, one end of which is hermetically sealed. The dark portion AB, represents mercury, which is retained in its position by the pressure of the atmosphere. It is connected with the receiver, by a screw at the extremity P. When the air has been so far rarefied that it can no longer support a column of mercury, even so limited in height as AB, that fluid begins to descend. If the vacuum formed were perfect —which can never be the case—the mercury would ultimately stand at the same height both in DB, and AB.

23. The air pump enables us to prove the elasticity, &c., of the air, by many interesting experiments. [illegible]*rter* is placed under the receiver A, fig. 174, when the

pressure of the atmosphere is diminished, the air which it contains, will convert it, to a greater or less extent, into froth.

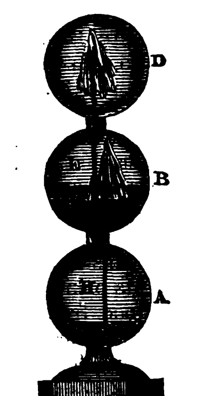
24. If an egg, which has a small aperture in its lesser end, is placed under the receiver, when the air is rarefied, its contents will be forced out, by the expansion of the small air-bubble contained in the larger end;—but they will return again into the egg, on re-admitting the air into the receiver.

25. If a shrivelled apple is placed in the receiver, and the air is exhausted, it will cease to be shrivelled:—since the air within it will expand; but on re-admitting the air, its plumpness will disappear.

26. If a lighted taper, or a living animal, is put into the receiver, the former will be extinguished, and the latter will die, when the air is exhausted. Chemistry will, hereafter, teach the reason of this. Some animals expire immediately; others, such as frogs, survive a long time. These experiments are cruel; and should not be made, except when—from the increase of knowledge acquired—the amount of good more than counterbalances the pain they inflict.

27. The fountain represented, fig. 176, illustrates both the rarefaction and condensation of air. It consists of three glass globes, A, B, and D, united by necks, but having no communication, except through the tubes H, and P:—the globe B, has an opening at E. When the apparatus is placed under the receiver A, fig. 174, on working the pump, the air in B rushes out through the aperture E, until what remains having become so rarefied, as that it can no longer counteract the pressure of the air which is above the water in A, that fluid is forced up through the tube H, and continues to form a jet, in B, until its surface has descended below the lower end of H. On re-admitting the air into the receiver, it passes freely through the tube H, the upper end

FIG. 176.



of which is above the water in B, but, presses on the latter, and forces it up through P—forming a jet in D, the interior of which contains only rarefied air.

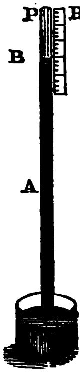
28. Pressure of the Air.—The air has weight. For a flask will weigh less when exhausted, than when full of air. The weight of a cubic foot of air is found to be about 523 grains. The pressure of the atmosphere may be illustrated by a simple experiment. A bladder is to be tied on the smaller end of a strong glass receiver, A, fig. 177, open at both ends, and ground at the larger, so as to fit, air tight, on the plate of the air-pump. When A is exhausted, the pressure of the atmosphere, no longer counterbalanced by a pressure from within, will cause the bladder to burst with great violence and a loud report.

Fig. 177.

29. If the edges of two brass hemispheres, which have been fitted together so as to be perfectly air-tight, are united—but without being fastened in any way, they will continue to adhere when the air is exhausted from between them, and, with a force proportionate to their size. Hence, if they are tolerably large, it will be impossible for any one, by mere muscular exertion, to pull them asunder.

30. The Barometer* is an instrument, intended to measure the pressure of the air, arising from its weight. It was invented by Torricelli, a disciple of Galileo, early in the seventeenth century, in consequence of a doubt entertained by the latter, that the ascent of water in pumps was due to what was then considered to be its cause—"nature's abhorrence of a vacuum." Torricelli soon suspected the true reason, and demonstrated it by means of the barometer.

Fig. 178.



31. Its principle, and mode of action, will be understood from fig. 178. The glass tube A, about 33 inches long, and hermetically sealed at one end, is filled with mercury, and—the open end being closed with the finger—is inverted in a cup of mercury D: the fluid in the tube imme-

* *Baros* weight; and metreo, I measure. *Gr.*

diately falls to some point B, the position of which depends on the pressure of the atmosphere. The empty space between P and B is called the *torricellian vacuum.*

32. Before the tube was immersed in the mercury, the surface of the latter sustained a pressure of about 15 lbs. to the square inch. But the pressure is now removed from over that part of it, which is within the tube—being transferred to the exterior of the hermetically sealed end of the latter. The pressure, therefore, on the surface within, is no longer equal to that which is outside:—hence [mech. 107] motion ensues, and the mercury is forced up into the tube by the atmospheric pressure, which is the greater; and it will continue to rise until, by its weight, it exactly counterbalances the action of the column of air which it has replaced. As the pressure of the atmosphere is variable, the column of mercury sustained by it, must be variable, also.

33. The barometer gauge [20] is exactly the same in principle, as the barometer; but its upper extremity, instead of being hermetically sealed, is connected with the receiver of the air-pump ; and, as the exhaustion proceeds, the mercury rises within it. If the vacuum in the receiver could be made as perfect as the torricellian, the mercury, both in the barometer and in the barometer gauge, would stand at the same height. But, since, as we have seen [19], some air still remains in the receiver, the pressure on the surface of the mercury within the gauge, is never completely removed. Hence, the column within is diminished —the pressure inside the tube, being made up, partly, of the pressure of the mercury, and partly of the pressure of the air which still remains above it; and the sum of both is just equal to the pressure of the mercury alone, in the barometer. The amount of exhaustion in any vessel, is measured by the number of inches of mercury, which are sustained in opposition to gravity.

34. It is evident that the real height of the mercury, in the barometer, is its height above the surface of the mercury, in the cup. Hence, as the latter is raised, by the descent of mercury from the tube, and *vice versa*, in good barometers, there is always some means of accurately comparing the level of the mercury in the tube, with that in the cup.

35. The barometer has been made to assume many forms; but the simplest is found to be the best. Every attempt to magnify the space through which the mercury ascends or descends—which is about three inches, the mean pressure being thirty inches—seems to be accompanied with a sluggishness of motion, or some other inconvenience, which diminishes the sensibility; and, therefore, philosophers content themselves with carefully constructed instruments, of the ordinary kind—the *vernier* being used to assist them in their observations.

It has been found that, from the want of perfect contact between the glass and the mercury, air gradually insinuates itself between them, and ascends into the tube. This is prevented by attaching, at a high temperature, a ring of platinum foil round the outside of the open end of the tube.

36. *The Water Barometer.*—Water has been used, instead of mercury, in the construction of a highly sensitive barometer. An instrument of this kind, in the hall of the Royal Society at Somerset House, consists of a tube of glass, forty feet long, and one inch in diameter. It is affected by changes in the atmosphere, which produce no alteration whatever in the best mercurial barometers.

37. The *Aneroid barometer** was proposed as a substitute for the mercurial, by M. Conte, in 1798; but it is said that the effect produced upon the instrument by changes of temperature, caused it to be abandoned by its inventor. It consists of a thin metallic vessel, in which the air has been highly rarefied, and which alters its shape, as the pressure of the external air varies. This change of shape is indicated, and measured, by a suitable contrivance. Though it is difficult to prevent alteration of temperature, &c., from interfering with the accuracy of this instrument, it has been found to agree very much with the ordinary barometer.

38. As we ascend from the surface of the earth, the pressure of the air, and therefore the height of the mercury in the barometer, diminishes; and the diminution is found to be, about one inch for every 992 feet of ascent. A knowledge of this enables us to measure the height of mountains. Let the barometer, for example, stand at a

* *A* privative; and aër, the air. *Gr.*

given height on the plain; and, at the same time, four inches lower upon the top of a mountain: we may conclude the height of the mountain to be $4 \times 992 = 3{,}968$ feet. In this experiment, inaccuracy will arise from not taking into account difference of temperature, which causes the bulk of the air to change, and consequently alters its density. Change of temperature is found to produce nocturnal and diurnal oscillations of the barometer. The rise and fall of the ocean appears also to affect it, since a variable base is given to a large portion of the atmosphere.

39. The air on the top of high mountains is sufficiently rare to affect respiration—to occasion a loss of muscular strength—to diminish the intensity of sound—and to make a fire be kindled, and maintained, with difficulty. Since the column of air in the torrid zone is higher, on account of the rarefaction caused by heat, the diminution of barometric pressure, consequent on distance from the general surface of the earth, does not proceed so rapidly as in the temperate, or frigid zones. Hence it has been found that the barometer does not sink more than half as much for a given number of feet of ascent, in the torrid, as in the temperate zones.

40. We may, with equal facility, estimate depths by means of the barometer. When the shaft of Monkwearmouth colliery—the deepest, perhaps, in the world—had reached to 1,500 feet below the level of the sea, the barometer stood, in the lowest part of it, at 32·280 inches, while one at the surface was at 30·518.

41. The barometer is sometimes, but inaccurately, called a *weather glass*. Undoubtedly, change of weather is generally accompanied by some change of atmospheric pressure; but the present state of our meteorological knowledge does not enable us to say, with certainty, what the corresponding changes are. It is clear that the indications, affixed to many barometers, and which are intended to mark the *precise* variations of weather, corresponding to the different heights of the column of mercury, are not to be relied on. For, if they were accurate, the weather should be different on the top of St. Paul's dome, and at the pavement around the church; since the indications of the barometer would be different, above, and below. The

only fact well ascertained, seems to be that, in very fine weather, the mercury is generally high; in wet weather, low; and in variable weather, changeable. The barometer is low also in great storms, of which we had a remarkable instance in the disastrous hurricane of January 6, 1839; on which occasion, the barometer was remarked to stand lower than at any previous observation. The barometer falls in damp weather, since, when dry air is saturated with moisture, it increases in bulk; for aqueous vapour is not so dense as atmospheric air, at the same temperature. In these countries, the barometer varies about three inches: at Naples, about one inch: and within the tropics scarcely at all.

42. The state of the barometer must be taken into account, when we estimate the volumes of gases and vapours [hyd. 61, and 64]. For, since their bulk varies inversely as the pressure [12], we cannot compare different volumes, with accuracy, unless we compare them when under the same pressure, or make the necessary correction. Thirty inches, the average height of the mercury, is the standard adopted. "The volume at any one pressure, is equal to the volume at any other multiplied by its corresponding pressure, and divided by the pressure belonging to the required volume."*

Example.—When the barometer stands at 27 inches, the volume of a given quantity of a certain gas in 38 cubic inches: what would be its volume, if the barometer stood at 30 inches?

$\frac{27 \times 38}{30} = 34{\cdot}2$ cubic inches, the required volume.

43. The actual density of a given portion of the atmosphere, depends on its specific gravity—which is affected by heat, cold, &c. Changes in the density of the air, are indicated by the *manometer*,† or *manoscope*.‡ These instruments have been constructed in various ways. Boyle formed one, which he called a "statical barometer," with

* Let a, be the volume, with a pressure b; and c, the volume, with a pressure d. Since the pressures are, inversely, as the volumes, $a:c::d:b$. Therefore $a=\frac{cd}{b}$: and $c=\frac{ab}{d}$.

† *Manos*, rare or subtile: and *metreo*, I measure. *Gr.*

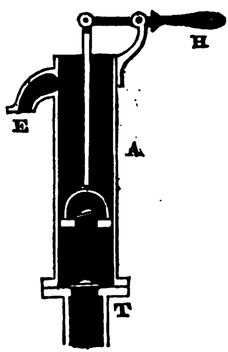
‡ *Manos*: and *scopeo*, I examine carefully. *Gr.*

a bubble of very thin glass about the size of an orange, balanced very delicately when the atmosphere was at a mean density. It descended if the air became lighter, and ascended if it became heavier.

44. PUMPS are of various kinds; but from what we have said of the condenser and air pump, it will be easy to understand their construction.

The house or suction pump.—The barrel A, fig. 179 is connected with a tube T by the valve D: a piston, —also, having a valve—works water-tight in A: and both the valves open upwards. When the piston is raised, by means of the handle H, the valve which it contains is closed, and the air below it, is rarefied [19]: after which, the air—or, at the end of a few strokes, the water—in T, on account of the external atmospheric pressure acting upon the surface of the water in the well or cistern connected with T, raises the valve D, and passes into the *lower* part of the barrel A. On depressing the piston, its valve is raised by the water under it, which passes into the *upper* part of A. When the piston is next raised, the water over it ascends higher, and, ultimately, issues out through the spout E—while an additional quantity flows through the valve D into A: and thus, as often as the piston is raised and depressed, the same effects are produced, if the proper supply is maintained by the pipe T.

FIG. 179.



Sometimes there is no valve at D: nevertheless, the water rises through P, when the piston is depressed—the latter being made to descend so rapidly, that the fluid has not time to flow down before it.

45. Since it is the pressure of the air that causes water to rise in a pump, the height to which it will ascend depends upon that pressure. When the barometer is at 30 inches, water will rise to the height of about 33 feet:—for a column of mercury, 30 inches, is nearly the same weight as a column of water, 33 feet high.

46. Water may be raised to a considerable height, by increasing the length of that part of the barrel A, which is above the piston. In such a case, however, atmospheric pressure has nothing to do with the additional distance, through which the water is lifted.

If the piston rod is very long, it is found to bend, unless there are guides within the barrel, at certain distances.

47. *The lifting pump.*—Water may be elevated, through a considerable height, by a modification of the suction pump, represented, fig. 180. When the piston P, is raised, by means of the handle H—the effect of which is transmitted through the rod SO, to CO turning on C—the air under it is rarefied, and the water ascends into the lower part of the barrel B. On depressing the piston P, the air—or, after a few strokes, the water—lifts the valve in P, and ascends above it: when the piston is next raised, the fluid over it ascends still higher, and, ultimately, passes into the pipe E—being prevented from returning, in each case, by the respective valve falling down into its seat.

FIG. 180.

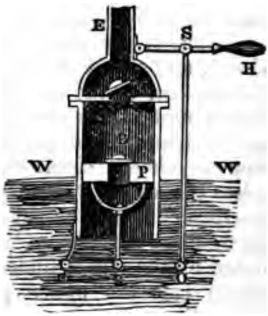
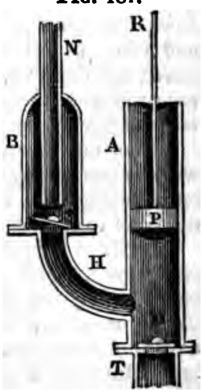


FIG. 181.



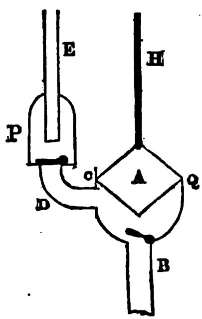
48. *The forcing pump* may be understood from fig. 181. It consists of a barrel A, in which the solid piston P, is movable up and down. A communicates with the pipe T, by the valve D; and, with the air-vessel B [16], by the pipe H, which also is closed by a valve;—both valves open upwards. When the piston is raised, the air under it is rarefied, since the valve in B is closed: and air—or, after a few strokes, water—rushes up from the suction pipe T, through the valve D. When the piston is depressed *D closes,* and the air or water, as the

case may be, rushes through the other valve into B; and, ultimately, passes up through the force pipe N. The air-vessel B is omitted, when a constant jet from N is not required.

The force pump, suitably modified, is used to supply the boiler of a steam engine with water. The piston, or "plunger," is a solid plug of metal, working water-tight through a packing box (to be described hereafter) in the barrel.

49. A very simple pump, applicable in some cases, may be understood from fig. 182. The vessel A is closed above by CQ—a piece of oiled cloth, vulcanized Indian rubber, &c. When this is drawn up by the handle H, the space in A being enlarged, a partial vacuum is formed, and fluid rushes in through the valve which is over B. When H is depressed, so that the cloth, &c., assumes the position indicated by the dotted lines, the space in A being diminished, fluid ascends into P, through the valve which is over D; and, ultimately, passes through E.

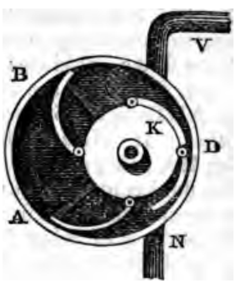
FIG. 182.



50. *The fire engine* consists of two pumps, standing in a cistern, and connected with an air-vessel. The cistern may be supplied with water by hand, or by a tube, &c. The pumps are worked with handles, which extend along at each side, and may be grasped by several persons at once. The water is conveyed, by a flexible tube and nozzle, to the spot where it is most required. The details may be variously arranged.

51. *The eccentric pump* consists of a drum ABD, fig. 183, having within it a solid cylinder, which is of the same length, but of little more than half the diameter of the drum. The flaps KK, &c., which are of the same curvature as the inner cylinder, are distended, dur-

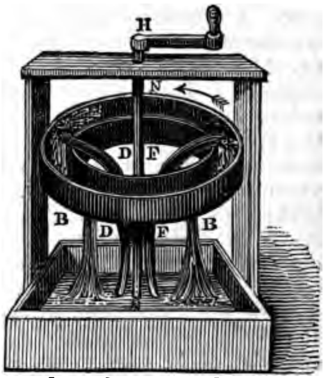
FIG. 183.



ing the revolution of the latter, by wires crossing each other at, and passing freely through, the solid cylinder. As they open, the vacuum produced inside of them, is supplied by the feed-pipe N: when they close, the water is forced up the pipe V. It is extremely difficult to keep the chambers of this pump from leaking into each other.

52. *The centrifugal pump* consists of tubes DD, and FF, fig. 184, united to, and turning on a vertical axis NN. When they are made, by means of the handle at H, to revolve rapidly, the water is thrown out at their upper extremities by centrifugal force [mech. 112]; and the vacuum produced causes the fluid to rush up into them, from the cistern, &c. The machine is always ready to act, on account of the water being retained in the pipes, when at rest, by valves—which are opened by the centrifugal force imparted to the water, during its rapid motion.

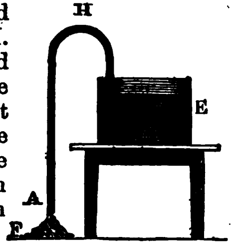
Fig. 184.



A very effective centrifugal pump, which seems to answer well for moderate heights, is constructed somewhat like the tangential turbine [hyd. 132]. Being made to revolve with great velocity in the direction of the arrow, fig. 164, a considerable quantity of water passes in at the centre from a pipe, and is thrown out at the circumference. Gravel, &c., produces no injury to the machine.

53. Syphons are bent tubes of glass, metal, &c., such as AHD, fig. 185—one of the legs being shorter than the other. If AHD is filled with any fluid, and—its longer leg HA being closed with the thumb, &c.—is immersed in the fluid contained in the vessel E, on removing the thumb a stream will issue from A, and will continue to run, until the surface of what is in the vessel is below the extremity of the leg HD. For, what is in AH descends by the force of gravity: so that a vacuum would be produced in

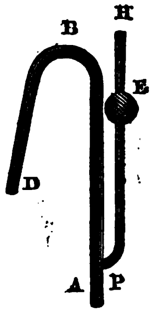
FIG. 185.



that leg, if the atmosphere, acting on the surface of the fluid in E, did not cause it to ascend through DH. The velocity with which the liquid escapes through A, depends on the difference between HA, and that part of HD, which is above the surface of what is in E. When they are equal, the two columns will be in equilibrio, and the fluid will remain at rest.

54. The syphon is extremely convenient for decanting liquors; and, the more easily to prevent the fluid from escaping before it is immersed, a cock is sometimes placed at the extremity of the longer leg. When used by chemists, &c., it is occasionally constructed as represented, fig. 186. A small tube HP, having a bulb at E, is inserted into the lower extremity of the longer leg BA. When BD is immersed in the fluid to be drawn off, A being closed by the thumb, the air in HP is drawn out, by sucking with the mouth at H. This exhausts ABD, and the fluid fills the syphon, so that, on removing the thumb from A, it immediately flows out. If reasonable caution is used, the bulb E prevents any danger of the fluid being drawn into the mouth—which, in many cases, might be attended with inconvenient, or even dangerous consequences.

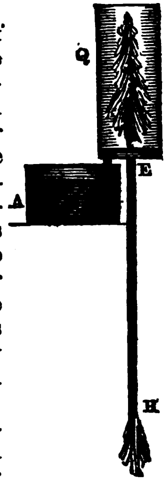
FIG. 186.



55. *The Syphon fountain* may be formed with a tall bottle, or a glass cylinder Q, fig. 187, which is closed above, and has tubes fitted air-tight into a cork, inserted into its lower extremity. If a small quantity of water is introduced into Q, and the shorter tube is placed in fluid contained in the vessel A, the air in Q will be rarefied—on account of the fluid, which is in it, flowing down through EH; and the atmospheric pressure, acting on the surface of what is in A, will force it up through the shorter tube—a jet being formed, which will continue until the extremity of that tube is no longer immersed. This instrument is

merely a syphon, somewhat enlarged in one portion.

FIG. 187.



56. SOUND is a series of vibrations of any sonorous body, communicated to the ear by any *medium* or intermediate substance—generally by atmospheric air. A fine membrane, called the *tympanum* or drum, stretched across a cavity of the ear, is the part most affected by sound—though it appears that* this is not indispensable to hearing. If the vibrations of the sonorous body are too slow or too rapid, they will be imperceptible. Under ordinary circumstances, sound cannot be produced without the presence of air—as we may demonstrate experimentally, by attempting to ring a bell in an exhausted receiver.

57. CONDUCTION, &c., OF SOUND.—Some bodies are found to transmit sound better than others: thus, wood better than air. This may be proved, by placing the ear at one extremity of a long beam of timber, and causing the other to be struck gently with a key:—the sound transmitted by the timber, will be heard with the greatest distinctness. Iron conducts sound still better than wood. M. Biot found, at Paris, that a watch, which was made to tick at one end of a cast-iron pipe, was heard perfectly well at the other; although the pipe was three or four miles in length. Communication is often maintained between very distant apartments, by means of tubes. And deaf persons have frequently been able to enjoy the pleasures of music, by holding in their teeth a metallic substance resting on the musical instrument.

58. *Velocity of sound.*—Whatever the intensity, quality, or pitch of sound, the velocity of its transmission through the same medium never alters. The following table exhibits the speed with which it is transmitted through certain substances, the rate which it passes through air being considered as unity:—

* Phil. Trans. 1800, &c.

Through	distilled water,	4·5,	according to	Laplace.
,,	sea-water, .	4·7,	,,	Ditto.
,,	tin, . .	7·5,	,,	Chladni.
,,	silver, . .	9·0,	,,	Ditto.
,,	cast iron, .	10·0,	,,	Biot.
,,	brass, . .	10·5,	,,	Laplace.
,,	copper, . .	12·0,	,,	Chladni.
,,	wood, 11·0 to	17·0,	,,	Ditto.
,,	hammered iron,	17·0,	,,	Ditto.

59. The velocity with which sound is transmitted by the air, depends on the state of the latter. According to Sir J. Herschell, it travels in dry air, when its temperature is 32°, at the rate of 1,089 feet in a second. Its velocity has, however, been very differently estimated by different persons. When conveyed by aeriform bodies, its velocity is inversely as the density of the medium—temperature and pressure being constant. When the height of the column of mercury in the barometer is altered—the temperature being constant—the velocity is not changed: for, then, both elasticity and density are equally increased, or diminished. When the temperature is increased, or diminished—the barometric column being unchanged—the velocity is increased, or diminished: for the elasticity, but not the density, is increased, or diminished. A rise in temperature of one degree, increases the velocity of sound 1·14 feet per second. An equal decrease of temperature produces a contrary effect.

60. The different rates, at which different bodies transmit sound, sometimes causes two sounds to be heard, instead of one—so as to produce the effect of an echo. Thus, if a cannon is fired across a frozen river, its report will be conveyed first by the ice, and afterwards by the air. Or, if the top of a wall is struck by a hammer, the sound will be heard twice at the bottom of it: first, when conveyed by the wall, and next by the air.

61. The *intensity of sound*, or its "loudness," depends, not on its pitch or its quality, but on the amplitude of the oscillations which constitute it: and is inversely proportional to the squares of the distances between the sounding body and the ear. It is affected by the rarity or density of the atmosphere. On a high mountain the voice is scarcely audible; in the diving bell, under water, it is disagreeably

loud. Its intensity is diminished by currents of air. The voice can scarcely be heard at the distance of a few yards, during a strong contrary wind.

62. The thermometric and hygrometric states of the air affect the intensity of sound. When the air is calm and frosty, it is often heard to a considerable distance. In Captain Parry's third polar expedition, Lieutenant Forster held a conversation across the harbour of Port Bowen, the distance being a mile and a quarter.

63. The intensity of sound is affected, also, by its original direction, and by the nature of the surface over which it passes. It is greatly lessened, when the sound is transmitted through media of different conducting power. Hence, the destruction of the homogeneity of the air, by alteration of temperature, is unfavourable to the transmission of sound;—and it is transmitted better by night than by day. Hence, also, a tall glass half filled with champagne, &c., cannot be made to ring, as long as the effervescence continues.

64. Sounds are diminished in intensity, by passing from solid to fluid, and still more to gaseous substances. Some bodies produce only a weak tone, from being incapable of imparting their vibrations, properly, to the air. Their effect is, however, heightened by *resonance*, that is, by their communicating them to another solid body, which, having a large surface, more easily affects the air: hence, the use of the *sounding board* in many musical instruments. Bringing the vibrating body, such as a tuning fork, &c., before a tube of proper length, renders the sound much more intense.

65. Hydrogen gas is almost as unfavourable to the transmission of sound as a vacuum. Hence the voice becomes small, when it is breathed—the lungs being filled with it.

66. As the air is compressed, during the undulations of sound, its temperature is raised: and the heat absorbed during the next rarefaction, is not equal to what was given out in the preceding compression—air being a bad conductor.

67. Sounds excited in air, are heard very indistinctly by a person immersed in water; but if excited in water,

they are conveyed to a considerable distance. A bell, struck under water, was heard across the Lake of Geneva, a space of about nine miles. Solid substances, cause but little interruption to sounds transmitted by the air; but render them almost inaudible, if transmitted by water. When all the circumstances happen to be very favourable, sounds are occasionally conveyed over very large distances. Thus the cannonading at Waterloo was heard in Dover.

68. *The quality of sound* is due to causes which are but little understood. Every one, however, has remarked the difference between the very same note, played on different kinds of instrument—or even on different instruments of the same kind.

69. MUSICAL SOUNDS.—The difference between ordinary, and musical sounds, consists in the greater rapidity of vibration of the latter. The more rapid the vibration, the higher the pitch. This is exemplified, by causing a metallic toothed wheel, about one foot in diameter, to revolve, and making the teeth, during revolution, strike against the edge of a card; when the velocity reaches a certain point, a humming noise will be heard; and, as the speed is increased, the sound produced will ascend through the scale. It is probable that the ancients used the expressions "high," and "low" tone, in a sense different from ours.

70. THE GAMUT.—When a musical note is sounded, it is accompanied by others, which are called its *acute harmonics*. If the note is sufficiently deep, these will not be too high to be appreciated by the ear. The range of hearing, generally though not always, includes nine octaves; but, as Dr. Wolaston remarks, the hearing of some animals may commence where ours terminates. The acute harmonics, which accompany the fundamental note, are its twelfth and seventeenth major—or the octave fifth, and double octave third above. Bernouilli believed, and it has been since established by experiment, that harmonies arise from subordinate vibrations of the strings, &c.

71. We find from this property of musical sounds, that the notes which constitute the gamut, have not been selected by chance, nor by the caprice of taste, but have been marked out by nature herself; and that in each key,

there can be neither more nor less than a certain number of flats, sharps, or naturals. If we examine the key of C, for example, we shall perceive that all its notes are harmonics of some one or more of the rest; and the entire scale will be formed from F, C, and G, three successive fifths—which may be arranged C, F, G, because, as far as harmony is concerned, a note and its octave may be considered the same. These three notes form what are called the "key note," the "sub-dominant," and the "dominant;" and their harmonics will give us all the notes in the key of C—substituting as we may, for the reason just given, the fifth, &c., for the octave fifth, &c. Thus

C gives, as harmonics, E and G
F " " A " C
G " " B " D

Which, placed in order, are C, D, E, F, G, A, B.

72. If we take the key of G, as another example, we shall learn in what manner sharps are obtained. Three fifths in succession will be C, G, and D—or G, C, D. And their harmonics will be—

From G, B and D
" C, E " G
" D, F " A

Which, placed in order, are G, A, B, C, D, E, F.

But in this key, the F is not the same as that in C. For, in the key of C it was natural, while in the key of G it is sharp. The reason of this will be obvious, if we remember that harmonics are a third and fifth *major*: but the major third is the fourth semitone; and the perfect fifth, the seventh semitone from the principal or fundamental note. Hence, the major third of D must be at the distance of two full tones from it, while there are only one and a-half between it and F natural—which, therefore, will be the *minor* third: for between D and E there is a whole tone; but between E and F, only half a tone. The major third of D will, consequently, be half a tone higher than F natural—that is, it will be F sharp.

73. We shall not find it hard to conceive that the harmonics and principal note may all sound together, if we call to mind that it is as easy for undulations of various *velocities* to co-exist in the air, as that waves in water

should pass over each other, and yet remain perfectly distinct—which occurs, if they do not differ too much in size.

74. We cannot change from one key to another, without *modulating*, as it is called—that is making proper preparation. For the ear must not change abruptly from sound to sound, since each succeeding sound, to give us pleasure, must be heard, more or less distinctly, as an harmonic of the preceding. Hence, except we pass from a major to a minor key, or *vice versa*, which we may do, because in such a case a sufficient preparation is made, we cannot, strictly speaking, increase or diminish the number of flats or sharps, by more than one at a time. We may, however, increase or diminish them by one. For, taking the key C as an example, its principal notes are F, C, and G: but the part of the scale of C, which is between C and G, belongs also to the key of G, the principal notes of which are C, G, and D. Hence, while we are between C and G, we may, without offending the ear, choose between either key; and pass, if we please, from one to the other: —if we choose the key of C, the F must be natural; if that of G, it must be sharp. The other methods of modulation depend on similar principles.

75. The preparation of the ear for the succeeding notes, is the great secret of melody. The ear can appreciate sounds which we are not able to describe; for, sensation does not cease so soon as the cause which produced it. Thus, if a stick, lighted at one extremity, is whirled round rapidly, we see a ring of fire:—not because the fire is in different parts of the circle at once; but because the sensations it produces, when in different parts, are co-existent, though their causes are successive. In the same way, the string, or the pipe, may have ceased to produce the sound, although the note and its harmonics have not vanished from the mind. Two rapidly succeeding notes may, therefore, be co-existent in the ear; and cannot be pleasing, unless, to a greater or less extent, they harmonize. Hence, though melody is a "succession," and harmony, a "union" of sweet sounds, it is certain that both derive the sources of the pleasure they impart, from very similar causes. Those nations which, like the ancient Irish, used stringed instruments, the construction and material of which ren-

dered it likely that, even in melody, one note should not entirely cease, until another had commenced, will be found, in their most agreeable airs, to have made successive emphatic notes near harmonics of the preceding—very frequently thirds, fifths, or octaves: the pleasures both of harmony, and of melody are, by this means, to a certain extent, united.

76. If two notes, each making an integral number of vibrations while a third makes but one, are sounded together, we shall, under favourable circumstances, hear also that third note—which is called a *grave harmonic.* The reason is obvious; a strengthened vibration occurs, when the vibrations of the two notes coincide; and this, being more effective than the other vibrations, gives the sensation of a distinct one, at intervals corresponding to the vibrations of the third note.

77. SYMPATHY.—If two instruments are tuned in unison and placed near each other, one cannot be sounded, without producing the corresponding note of the other: this is very evident with a stringed instrument—a pianoforte, for instance. Such an effect is termed "sympathy," and can be easily exemplified with a violin and piano. We shall find, on sounding any note of the former and suddenly causing it to cease, that—if the damper has been previously raised—the corresponding note of the latter will be heard. This principle may be further developed if, by means of the pedal, we raise all the dampers, and place pieces of paper across the third, fifth, and octave of the note we sound on the violin:—the pieces of paper will be thrown off the strings, by their being made to vibrate sympathetically.

78. If we put pieces of paper on the centres of the two halves, and on the middle of any string of a piano, and sound the note an octave below on the same instrument, the pieces on the centres of the halves will be thrown off, but the piece on the middle will not be disturbed. This shows that the string has divided itself into two halves, each of which sounds in unison with the string which was struck; while there is in the middle a *node*, or point completely at rest. These experiments may be varied; but their results can be anticipated, from what we have said.

The nature of sympathy, enables us to understand why an instrument, which is well tuned—independently of its accuracy—has a finer tone: the various notes, being more nearly harmonics, strengthen the effect of each other.

79. Sympathy is not confined to musical instruments; it seems, in a greater or less degree, to affect every substance in nature. That is, every substance has a rate of vibration, proper to itself; and is easily set in motion, provided any thing, vibrating at its own rate, is sufficiently near. Wine glasses, and even mirrors, have been, from this cause, sometimes broken by singers; and, as Boyle remarked, we frequently perceive a book, seat, &c., to vibrate at certain notes. The vibration is communicated by the air, and gradually increases in strength—the effect being due, not to the loudness of the note, but to its coincidence with the rate at which the body naturally vibrates. If we wet the edge of a drinking glass, and rub the finger round it, the vibration—at first extremely small—may, by constantly receiving new impulses, increase to such an extent, as that the glass will fly in pieces. These facts explain the breaking down of a suspension bridge, some years ago, at Manchester. Soldiers were passing over it—at first, in disorder, and without any injurious effect; but the band having begun to play, they commenced a regular march, the time of which, unfortunately, corresponding with the rate of vibration of the bridge, the latter gave way, and the soldiers were precipitated into the river. Thus, it is perfectly possible that a storm—or even, under certain circumstances, the continued effort of a single individual, might destroy a bridge capable, when at rest, of sustaining an enormous weight.

80. Ellicot remarked, that two clocks fastened to the same board, or standing on the same pavement, will beat together: though, separately, their rate of going may be different. The pendulum of a clock in motion, has been known to cause another, at rest, to vibrate, and at its own rate. It has even been remarked by clockmakers that, if the heavy weight of a large clock passes in front of, and very near the pendulum, it interferes with its rate of vibration:—the weight will begin to oscillate of itself, though a board is interposed between them; and their mutual action

will decrease, according as they become more distant from each other.

81. We avail ourselves of this property of bodies, to cause the very large pipes of organs to speak rapidly. The columns of air within them being considerable, time is required to put them in motion [mech. 6]: but this is greatly abbreviated, if we sound, at the same instant, a small pipe, some octave above the great one.

82. We cannot alter the rate of vibration, which is proper to a given body. If one end of a string is attached to a wall, &c., and the other is held in the hand, whatever amount of force we use, we cannot make it vibrate with greater than a certain rapidity—dependent on its length, and thickness. When we attempt to increase this rate, the string will form itself into parts, each of which will vibrate separately; and the greater the force we use, the smaller these parts will be. From this cause, an Eolian harp, having but one string, is capable of giving a variety of tones—according to the strength of the wind. When we blow gently into a pipe, we sound its fundamental note; but if we blow with increasing force, we produce the twelfth, then the fifteenth—or double octave: and the seventeenth, nineteenth, &c., will follow in succession. It is on this principle that the various notes are obtained, in certain instruments.

83. TEMPERAMENT.—The time of vibration of a given body, depends on its nature. We shall consider only strings and pipes; but the same laws govern the other sources of musical sound. The time of vibration of a string depends on its length, thickness, and tension conjointly.

84. If the tension and thickness are constant, it depends on the length. Half the length, will give a vibration twice as rapid; double the length, a vibration half as rapid, &c. Hence, the octave above a given note will require half, and the fifth above, two-thirds of the string which produces that note.

85. We may arrive, by calculation, at the seventh octave above, either by fifths or octaves; but the values we obtain will be different. The string, or pipe, corresponding to each fifth above, will be, in length, two-thirds of that *belonging to* the preceding. And the string, or pipe, cor-

responding to each octave above, will be, in length, one-half of that belonging to the preceding Taking C, as an example, calling it unity, and calculating by fifths, we find $\frac{4096}{531441}$ to be the value of the seventh octave above. Calculating by octaves, we find it to be $\frac{1}{128}$. And the values obtained for B sharp and C natural, which are the same note in most instruments, will be as $\frac{4096}{531441} : \frac{1}{128}$; that is, as $\frac{524288}{68024448} : \frac{531441}{68024448}$, or as $524288 : 531441$.

86. This difference of value for the same note, according as we calculate or tune by fifths, or by octaves, accounts for the variation of effect, if an organ, piano, &c., is tuned by fifths in one case, and by octaves in another. For, if the instrument is in tune by fifths, it will be out of tune by octaves. The adjustment of the interval, so as to cause the effect to be as little perceptible as possible, is called "temperament:" it is only a choice of evils, however, since most of the notes are thrown by it, to a slight extent, out of tune. To understand the nature of the correction made in the intervals, that the inconvenience arising from this difference in the values of the same note, or as it is technically termed, the "wolf," may be avoided, it must be observed that the more perfect a chord is, in its own nature, the more intolerable it becomes when inaccurate. But octaves are more perfect than fifths, since their vibrations more frequently correspond: and hence, if *either* fifths or octaves *must* be out of tune, we prefer making the former inaccurate—the inaccuracy being however so divided, as that it becomes scarcely perceptible. In such a case, we consider notes as the same—for instance, A sharp and B flat—which are really different; but we, by this means, avoid multiplying the notes to an inconvenient extent. For the greater accuracy of the intervals, instruments have been constructed—among others, the organ in the Temple Church, London, the double action pedal harp, &c.—in which these, and notes similarly circumstanced, are made, in reality, different.

87. The following are the rates of vibration, and relative lengths of the different notes in the scale—

Names of the Notes, . . .	A	B	C	D	E	F	G	A
Relative Number of Vibrations, .	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Relative Length of Strings, . .	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

An open pipe, 32 feet in length, will make 32 semi-vibrations in a second; and will produce the deepest tone we use in music. The sharpest tone requires about 15,000 vibrations in a second.

88. TUNING OF PIPES, STRINGS, &c.—The pipes of musical instruments owe their rates of vibration, not to the material of which they are formed, but to their length. Their cross section has but little effect—except as to the quality of their tone. Shortening a pipe renders the sound it gives more acute.

89. Pipes, when stopped by a plug, produce a note which is an octave deeper than that which is emitted by others of the same length, but open; because, in the former case, the vibrating column of air is twice as long. For it is found that the column in the open pipe divides itself into two equal parts, each of which vibrates separately. A stopped pipe is tuned by pushing in or drawing out the plug, according as the tone is too grave, or too acute.

90. Increasing the length, or thickness, of a string, causes it to yield a deeper tone:—the depth is, however, more rapidly increased, by adding to its thickness, than to its length. It is not the absolute, but the "vibrating," length which is to be taken into account: that is, the length between the two points, at which it comes into contact with other bodies—and beyond which its vibrations do not extend.

91. The number of vibrations made by a given string, is as the square of the force with which it is stretched. Thus, if it is stretched by a certain weight, doubling the latter will produce four times the number of vibrations.

92. When rods, or bars, of metal are fixed at one end, and made to vibrate, the number of vibrations is inversely as the squares of their lengths, and directly as their diameters. Thus, a bar half the length of another, will give four times as many; but a bar twice as thick, will give twice as many vibrations.

93. Deep tones are, sometimes, produced by very simple means. A spiral spring of tolerably thick steel wire, when struck, emits a sound very like that of a large bell, and is often used in time-pieces, &c., which strike the hours. If *a poker is suspended* by a cord, the ends of which are held

in the teeth—or one of them in each ear—and struck with a metallic substance, extremely deep sounds will be heard.

94. Chladni discovered that curious figures may be formed with sand, scattered on a pane of glass, which is fixed in a vice, &c., if the bow of a violin is drawn across the edge of the glass. It is known that these figures depend on currents of air, set in motion by the vibration of the glass; and that their peculiar form arises from the relative position of the fixed point, and that across which the bow is drawn. Galileo remarked that a bristle vibrates, when placed on the sounding board of a musical instrument. If paper, or parchment, is stretched over the mouth of a large bell-shaped tumbler glass, and fastened at the edges, while wet, with gum, &c., sand on its surface will assume the figures of Chladni, when it is held beneath a plate of glass, under which a bow is drawn. The paper, &c., should, as soon as it is dry, be varnished, to prevent its being affected by atmospheric changes. This instrument is so delicate, that it will be acted upon by sounds that are inaudible. Notes played near it, produce upon it a powerful effect—which depends on its position, with reference to the musical instrument. The besieged have, sometimes, ascertained in what direction a counter mine was being worked, by sand scattered on a drum-head.

95. Reflection of Sound.—Sound, when reflected, follows the laws of perfectly elastic bodies [mech. 136], making the angles of incidence and reflection equal. Reflected sound is called *echo*. The velocity of direct and reflected sound is the same. Hence, as we know the rate at which it travels [59], if we know how long it has been moving, we can easily tell the distance of the reflecting body: for it will always be equal to the number of seconds, multiplied by $\frac{1082}{2}$. As the sound has both to go to, and return from the reflecting body, the distance of the latter is half that through which the sound has passed.

96. It is necessary for the production of echo, that the direct and reflected sounds shall not occur at too small an interval—or [75] they will form but one sensation in the ear. Experiment shows, that the direct and reflected sound will not produce separate sensations, if the reflecting body is at a less distance than about 57·1 feet; for sound will

travel twice that distance in the tenth of a second, which is the smallest interval between two successive impressions, forming distinct sensations. Such an echo will give only a monosyllable. There are some very remarkable echoes: among others, that at Woodstock Park, which is said to repeat, very distinctly, 17 syllables in the day, and 20 at night. There is also a very fine echo at Killarney.

97. Concentration of Sound.—Sound may suffer reflection in such a way as to be concentrated to certain points, at which it will be distinctly heard, though, otherwise, but slightly or not at all audible. This is the principle of whispering galleries, the most celebrated of which is in the dome of Saint Paul's, at London. It is said, likewise, to be the principle of the hearing trumpet used by deaf persons:—the sound received at the wider end H,

Fig. 188.

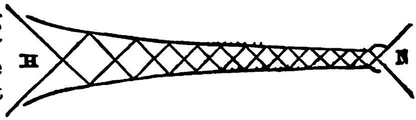
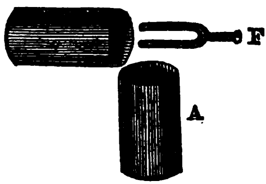


fig. 188, is condensed, and concentrated at N, the narrower, which is placed next the ear. Also of the speaking trumpet, which is of the same shape, but receives the sound at its lesser end. The air at the mouth of the instrument is affected by an impulse, which is as much greater than it would have been in ordinary circumstances, as the surface of the air at the mouth of the trumpet is less than the surface of a sphere, having the trumpet for radius. Leslie, however, and others, appear to have proved that the trumpet has no other effect than giving to the air, as it were, a greater density, by preventing it from escaping with facility: which enables the organs of the voice to act more powerfully upon it. The confined air of narrow passages, &c., increases the intensity of sounds, for the same reason. If the effect of the speaking trumpet, &c., were due to reflection, much would depend on the shape of its surface. But this is not the fact; for Hassenfratz showed, at Paris, that a cylindrical trumpet conveyed to the ear the ticking of a watch, placed in its mouth, as well as a conical one.

98. Interference of Sound.—Sound being a vibration of the air, we can easily conceive that two sounds, the vibrations of which happen to be exactly opposed to each

other—either individually, or at certain corresponding intervals—should, to a greater or less extent, produce silence; which is found, by experiment, to be the case. For, if we tune two large organ pipes nearly in unison, when they are sounded *together* certain intervals of silence will be perceived, and arise from this cause. We may illustrate the interference of sound, by a tuning-fork F, fig. 189, and two cylinders of glass A, and B. If the fork, while in a state of vibration, is placed over the mouth of the cylinder A, a sound will be heard; but if B is, at the same time, held at right angles, the sound will cease. The vibrations of the two glasses destroy each other.

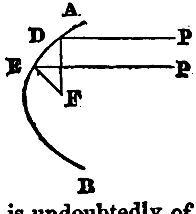
FIG. 189.



99. BUILDINGS FOR PUBLIC SPEAKING.—Distinctness of pronunciation is more useful, as a means of rendering public speakers audible, than all the assistance which art can give: and, by means of it, many persons are heard much more perfectly and at a greater distance, than others who possess far more excellent voices, but who pay little or no attention to this very important consideration.

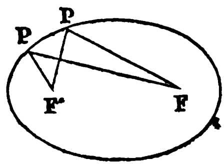
100. Any thing which tends to prevent the voice from being dissipated in the upper parts of the building, must be advantageous to the speaker: hence, *sound-boards* are placed over chairs and pulpits. But these ought not to be such as to concentrate the sound in certain points: because it follows, from principles to be explained when we shall speak of the foci of lenses and mirrors, that the more we strengthen sound in these points, by reflection, the more we diminish its effect in others. The parabolic sound-board seems to be the best; since the parabola has the property of reflecting all the rays of sound, which emerge from its focus F, fig. 190, in parallel lines, DP, EP—the angles of incidence and reflection being then equal.

FIG. 190.



101. The shape of the building itself, is undoubtedly of importance. It is evident that the elliptic form will be the

Fig. 191.



best, only when we desire that all the sound emitted from one focus F, fig. 191, should converge to F′, the other. Lines drawn from the foci to P, P, any points of the curve, would represent the direction in which sounds emitted in one focus would be reflected towards the other; since it is the property of the ellipse, that these lines make equal angles with the curve at P, P, &c. And, therefore, they will represent the equal angles of incidence and reflection, made by sounds proceeding from either focus, and reflected by the curve.

102. The nature of the walls and floor of a building, intended for public speaking, is not to be neglected. If the walls have many openings, the sound will be absorbed, very little being reflected among the audience; and, it is evident, that the voice will not be so effective in a room, &c., containing a number of recesses. If there are vaults, &c., under the floor, and the space between the latter and the arches is not filled with sawdust, or some other substance capable of intercepting the vibrations arising from the proximity of the hollow space, an effect highly injurious to the speaker will be produced. Some buildings are peculiarly favourable to the voice. Yet their excellence is the consequence of causes and conditions not easily discovered; and is seldom due, entirely, to the skill of the builders.

103. Ventriloquism is the power of imitating an absent, a distant, or a different person:—it derives its name from the fact that those who possess it sometimes seem to speak within their own stomachs.* This, however, was more true anciently than at present. Ventriloquism has often been perverted to the worst purposes; and is supposed to have been used in the ancient oracles. Its nature has given rise to much inquiry. Perhaps the most correct opinion is, that it consists merely in an accurate perception of the difference of sound, consequent on difference of distance or of circumstances, and a facility of expressing this difference—which is acquired by a good ear and much practice: and that it does not require any peculiar formation of the organs.

* *Venter*, the stomach; and *loquor*, I speak. *Lat.*

104. THE WIND is air in motion. It arises from various causes, which produce, in particular places, an increase or diminution in the bulk of the atmosphere. Among these, are the absorption of vapour during evaporation, or the loss of it by the production of rain; and the rarefaction of the air, due to an increase in its temperature, which rendering it specifically lighter, causes it to ascend—when the heavier portions then flow in to supply its place. These circumstances produce winds of greater or less duration; and atmospheric, like tidal currents [mech. 18], are modified by the different velocities of the air, according as the place whence it has come is more or less distant from the poles.

105. The difference between the temperature of the land and sea during the day and night gives rise, in hot countries, to *land* and *sea breezes:* the current being from the sea, in the evening, and from the land, in the morning. For, the temperature of the water being more uniform than that of the land, the former is colder by day, and warmer by night, than the latter; since, as fast as the surface of the water cools at night, it is replaced by a warmer, because a lighter portion.

106. It is ascertained that there are different currents of air, at different heights from the earth: indeed clouds, in a higher region, are sometimes driven by the wind in one direction; while those in a lower, are carried in the opposite.

107. ANEMOMETERS* are instruments, used for ascertaining the force of the wind. They are of various kinds: —in some of them, the wind is made to raise mercury in a tube properly bent for the purpose; and they are, even, so constructed, as to record the force and direction of the wind, at the different periods of the day and night. Sometimes water is employed instead of mercury.

108. Doctor Hutton gives the following results, water being used. When the fluid was raised

Inches.			Lbs. to the sq. ft.		Miles per hour.
$\frac{1}{4}$	the force of the wind	was	1·3;	and its velocity	18
1	,,	,,	5·2	,,	36
4	,,	,,	20·8	,,	76
8	,,	,,	41·7	,,	101·6
12	,,	,,	62·5	,,	124

* *Anemos*, the wind; and *metreo*, I measure. *Gr.*

Since a cubic foot of water weighs 62·5 lbs. neaı square foot, one-fourth of an inch in height, weigh forty-eighth part of 62·5 lbs., or 1·3 lbs.

109. The force of the wind [hyd. 69] is as the squ‹ its velocity. It travels at the rate of 100 miles per and upward, only in great storms.

CHAPTER VI.

OPTICS.

1. DIVISION OF THE SUBJECT.—Optics* is a science, which treats of the nature of light, and of the laws by which it is governed, but principally of the latter. It was not unknown to the ancients:—Ptolemy wrote a treatise on it, which is lost.

It is divided into *Dioptrics*, *Catoptrics*, *Chromatics*, and *Double Refraction*—which includes *Polarization.*

2. SOURCES WHENCE LIGHT IS DERIVED.—Light is either natural, as that of the sun; or artificial, as that which is emitted by a lamp, &c. Putrescent substances, particularly fish and wood in a state of decomposition, emit light, which is not affected by a blast of atmospheric air, or oxygen: the light however from fish, is sometimes, and that from wood, is always, extinguished by nitrogen.

* *Opto*, whence; *optomai*, I see. *Gr.*

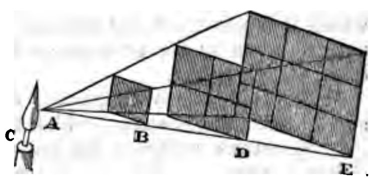
The emission of this kind of light is prevented by hydrogen, carbonic acid, sulphuretted hydrogen, &c.

3. NATURE OF LIGHT.—There are two opinions on this subject: that of Newton, called the theory of "emission," according to which, light is a very subtile matter, thrown out from luminous bodies; and that of Huyghens, called the "undulatory" theory, according to which, it is not a material substance, but the vibration of a highly elastic and very subtile fluid, as sound [pneum. 56] is the vibration of air. With regard to the more ancient opinions on this subject—for instance, that luminous bodies are perpetually throwing out *spectra* or images, &c., we pass them over in silence, as altogether absurd.

4. The undulatory theory is now almost universally adopted. And it seems favourable to the opinion of universal space being pervaded by a very subtile fluid, that the observations made by Encke, on the comet bearing his name, indicate a retardation of that body, by such a fluid. Sir I. Newton has shown that this ethereal fluid, if it exist, is 700,000 times less dense than atmospheric air. In producing the various colours, it vibrates with amazing rapidity:—scarlet requires 458 millions of millions of vibrations, in a second; and violet, 727 millions of millions.

5. Light is emitted from a luminous body C, fig. 192, in all directions, and in straight lines. As these lines continually diverge, the spaces, B, D, and E, over which they are spread, continually increase, and by consequence, the intensity of the light diminishes to the same extent. That is, the intensity varies inversely as these spaces; and the latter vary as the squares of the distances AB, AD, and AE. A luminous body will, therefore, give four times as much light, at the distance of one foot, as at the distance of two feet: and nine times as much, as at the distance of three feet.

FIG. 192.



6. When light is thrown upon any thing, it is either

absorbed, transmitted, or reflected: or more than one of these effects is produced—indeed some light is always absorbed. When the body is *opaque*, that is, incapable of transmitting light, there is formed behind it a shadow, which continually increases if the luminous body is less than the opaque, but continually diminishes if it is greater: in the latter case, when the luminous body is considerable, there is around the true shadow a half shadow which constantly increases, and is due to the light from some parts of the luminous—but not from others—being intercepted by the opaque body. Certain substances are *transparent*,* that is, allow an object to be distinguished through them: as glass, &c. Some are *translucent*,† that is, allow the passage of light, but in so confused a mass, that nothing can be distinguished through them: such, for example, are paper, muffed glass, &c.

The smallest conceivable portion of light is termed a *ray;* and whatever affords a passage to light, is called a *medium*.

7. Light travels at the rate of 192,000 miles in a second. This is known, by the time it takes to pass across the earth's orbit—which is estimated by the additional time, required for an eclipse of a satellite of Jupiter to become visible, when the earth is at a part of its orbit farthest from that planet. Were light a material substance, its particles should be inconceivably minute; since, notwithstanding their enormous velocity, their momentum would be such as to cause no inconvenience to an organ so delicate as the eye. Light travels from the sun to the earth, in about seven and a-half minutes:—its position, with reference to us, is in the meantime changed.

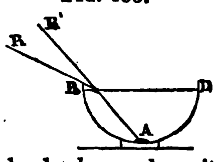
8. M. Arago remarks, that light from a self-luminous body may be distinguished from that which is reflected, by its continuing visible, at any distance—provided the luminous body remains of a sensible diameter. A body seen by reflected light, may, on the contrary, vanish while its diameter is still considerable. When light comes from a self-luminous body, its brilliancy is inversely as the square of the distance [5]. If, therefore, we look at a

* *Trans*, through; and *appareo*, I appear. *Lat.*
† *Trans;* and *luceo*, I shine. *Lat.*

self-luminous body, through a small aperture, wherever the aperture may be situated, the brightness of the body will be still the same: for if, on the one hand, it is diminished as the square of distance is increased, on the other, it is augmented to the same extent, by a larger portion of the luminous body coming into view. Uranus is 19 times farther from the sun than our earth; hence, to an inhabitant of that planet, the sun appears like a star, the diameter of which is 100 seconds: that is, it must have the same brilliancy, as if seen by us through an aperture of 100 seconds. For the weak light of the whole disc, as seen at Uranus, is just equal to the strong light from a part of the disc, as seen by us through the aperture: and it will be visible, so long as it is of a sensible magnitude—just as we can see it through an aperture, so long as the latter is of a sensible magnitude. When the body is not self-luminous, its light is not radiated, and, therefore, its intensity is not "inversely as the square of the distance." Since comets become dim before they cease to be of a sensible magnitude, it is to be inferred, that they do not shine by their own, but entirely, or to a great extent, by a reflected light.

9. DIOPTRICS.*—REFRACTION.—Under this head, are considered the laws which relate to *transmitted* light. When light passes from one medium to another, of greater or less density, it is always *refracted*;† that is, turned out of the same right line, but, ordinarily speaking, not out of the same plane. The refraction of light may be illustrated by a very simple experiment. If a stick is immersed in water, &c., however straight it is in reality, it will in appearance be broken, where it enters the fluid. Or, if a shilling A, fig. 193, is placed in a basin of water BD, when we stand in such a position that it will just be visible from R, over the edge, it will cease to be seen from the same point, should the water be removed:—because the path of the ray will change from ABR to ABR′, since it will no longer be refracted.

FIG. 193.



* *Dia*, through; and *opto*, I see. *Gr.*
† *Re*; and *frango*, I break. *Lat.*

Euclid remarked the effect of refraction, illustrated by this experiment: but the ancients were better acquainted with catoptrics than with dioptrics. Since an object appears in water about one-fourth higher than it really is, the depth of a river is greater than it appears. Many accidents have happened on account of persons mistaking the depth of water, from this cause.

10. When a ray falls perpendicularly on the surface of a medium, there is no refraction. Since the sun is never in our zenith, refraction, also [7], prevents it from appearing to us in its real place.

11. The constant relation between the sines of the angles of incidence and refraction is called the *ratio of the sines*, or the *index of refraction*. Ptolemy, the astronomer, noticed the existence of some such relation. It has been ascertained, for a number of substances: of which the most remarkable are the following.

We shall, for convenience, consider the angles of incidence, refraction, reflection, and polarization, as made by a ray with a *perpendicular* to the surface [mech. 136], and not with the surface itself.

	Index of Refraction.
Chromate of lead (highest refraction),	2·974
——— (least refraction),	2·500
Diamond,	2·439
Glass (lead, 3; flint, 1),	2·028
—— (lead, 2; sand, 1),	1·987
—— (lead, 2; flint, 1),	1·830
—— (lead, 1; flint, 1),	1·787
—— (lead, 3; flint, 4),	1·732
—— (lead, 1; flint, 2),	1·724
Mother of Pearl,	1·653
Flint glass, from 1·625 to	1·590
Bottle glass,	1·582
Rock salt,	1 557
Melted sugar,	1·554
Amber,	1·547
Plate glass, from 1·542 to	1·514
Crown glass, from 1·534 to	1·525
Oil of Turpentine,	1·475
Alcohol,	1·372
Salt water,	1·343
Crystalline lens of the human eye,	1·384
Air (Biot), barom. 30·17, thermom. 32°,	1·0009295

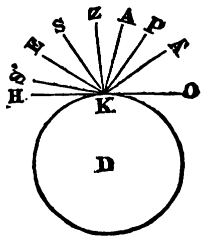
Gases, according to Dulong.

	Index of Refraction.
Hydrogen, ...	0·470
Oxygen, ...	0·924
Atmospheric air, . . .	1·900
Nitrogen, ...	1·020
Ammonia, ...	1·309
Sulphuretted hydrogen, . . .	2·187
Sulphuret of carbon, . . .	5·179
Sulphuric ether, ...	5·280

12. Although, with the same surface, the angles of incidence and refraction have the same ratio, the refraction increases with the obliquity of the incidence.

13. We cannot rely on celestial observations, made within ten or twelve degrees of the horizon, on account of the density of the atmosphere being subject there to irregular variation. The quantity of refraction, at the same distance from the zenith, varies nearly as the height of the barometer, the temperature being constant. Every rise in temperature, equal to a degree Fahrenheit, diminishes refraction by about the $\frac{1}{480}$th part. The refraction of the atmosphere is not affected by its hygrometric state. Dr. Bradley found, by calculation, the amount of refraction corresponding to each altitude.* The twinkling of the stars arises from sudden changes in the refractive power of the air—which would be imperceptible, if they had discs, like the planets.

FIG. 194.



* He used the following method:—Let K, fig. 194, be the position of a spectator on D, the earth. Let HO be the horizon; P, the pole of the equinoctial E; A, the highest place of a star very near P, and A′ its lowest place; let S be the sun's greatest altitude, S′ its least; and Z the zenith. A, on account of the earth's rotation on its axis, will seem to revolve round P; then AZ will be the star's least, A′Z its greatest zenith distance; and, but for refraction, AZ+A′Z= 2ZP. Again, ZS is the sun's distance from the zenith at its least, and ZS′ at its greatest altitude; and, but for refraction, ZS+ZS′=2ZE. But 2ZP+2ZE=2ZO=180°. Therefore, but for four refractions, AZ+A′Z+ZS+ZS′=180°.

14. High refractive power indicates inflammability in the substance which possesses it. The knowledge of this law induced Sir I. Newton to foretel that the diamond would be found to be combustible: a prediction since verified.

15. When a ray passes from a less to a more dense medium, it is turned *towards* a perpendicular to the surface of the medium; when from a more to a less dense medium, it is turned *from* a perpendicular to the surface.

16. The most transparent substances absorb some light, as it passes through them. The density of the stratum of air, at the horizon, causes it to diminish the sun's light, during transmission, 1,300 times. Hence, we can look at the sun, when in the horizon, without being dazzled.

17. Bodies act on rays of light before they come in contact with them:—shadows, therefore, are larger than they ought otherwise to be; and a knife-edge will turn light out of its path.

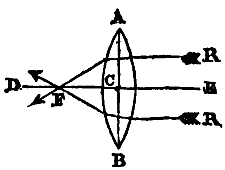
18. A *pencil* of rays is a portion of light distinct from the rest. Rays are either *parallel*, *converging*, or *diverging*.

19. The *focus** is a point towards which rays converge; it is *real*, when the rays actually meet; *imaginary* or *virtual* when, to make them meet, they must be produced. The word "focus" is very appropriate, since rays of light, in sufficient quantity, when concentrated to a point, have the power of burning.

20. The *principal* focus is that of parallel rays: or the point to which the rays, entering the lens in a parallel direction, converge after leaving it.

21. The *geometrical* focus is a point F, fig. 195, at which rays RR, supposed to be indefinitely near ED the axis of the lens AB, intersect each other.

FIG. 195.

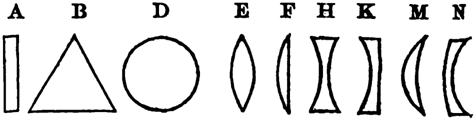


22. A *lens* is a "medium," having at least one surface convex or concave.

23. The forms which media are most usually made to assume, for the purpose of refraction, are, the parallel plate

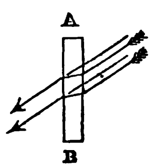
* *Focus*, a fire-place. *Lat.*

FIG. 196.



A, fig. 196; the triangular prism B; the sphere D; the double convex lens E—of which the convexities may be either equal or unequal; the plano-convex lens F; the double concave lens H—of which the concavities may be either equal or unequal; the plano-concave lens K: the meniscus M; and the concavo-convex lens N.

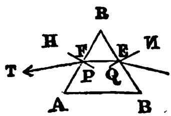
FIG. 197.



24. *Refraction through a plane glass.*—Neither the parallelism, convergence, nor divergence of rays, is altered by transmitting them through a glass plate AB, fig. 197, having parallel surfaces. But it changes the real, though it does not affect the relative position of objects RR.

25. *Refraction through a prism.*—The index of refraction, for the substance of which a given prism is made, being known, it is easy to find the paths of a ray DT, fig. 198, making an angle DEN with NQ, a perpendicular to the first surface RB. For [11] we know the ratio of the sines of DEN, and FEQ, the angles of incidence and refraction, at the first surface. We know also TFH, the angle made by the emerging ray, with a perpendicular to the second surface AR: for we know the ratio of the sines of EFP, and TFH, the angles of incidence and refraction at the second surface.

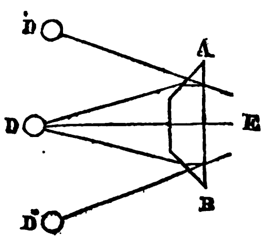
FIG. 198.



26. Since a single ray of light must be inconceivably small, when it touches a curved surface, it may be supposed to touch a tangent plane coincident with that surface:—for any curved surface can, without sensible error, be considered as made up of an infinite number of plane surfaces. But, when the latter becomes of a sensible extent, their effect is greatly altered. Hence, if a curved surface is ground into a number of small plane surfaces, any object seen through it will produce as many images as there are

surfaces: because each surface is large enough to transmit a separate parcel of rays—capable of giving a distinct, but not a magnified, image; and an object is imagined to be in each of the directions from which the different parcels of rays come. This may be understood from fig. 199. One side of AB is supposed to consist of three plane surfaces—the number is of no consequence: each of them transmits distinct parcels of rays, and produces, therefore, a separate image of the object D. Such an instrument is called a *multiplying glass*. When each indefinitely small surface, into which the general surface of any medium is divided, is capable of transmitting only what may be considered as a single ray; it can, evidently, give to the mind no idea of any object; for, as the ray comes from but one point, there are many points from which each of the indefinitely small surfaces transmits no rays. Hence, when glass is *muffed*—that is, rendered rough, though it continues *translucent*, it ceases to be *transparent*. It has been made to consist of a vast number of small surfaces, which are capable of turning the rays in all possible directions, but which are not large enough, individually, to transmit so many rays as are required to form the image of an object. The particles of the atmosphere, in this way, disperse on all sides the rays which come from the sun, and fill the space around the earth with light. Without an atmosphere, that luminary would be a bright globe, suspended in a dark sky; and while the sides of objects next to it would be extremely bright, their other sides would be quite dark and invisible.

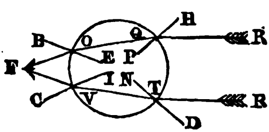
FIG. 199.



Some of the effect of the atmosphere is due to reflection.

27. FOCI OF LENSES.—F, fig. 200, the principal focus of a sphere, which may be considered as a prism formed by planes tangential to its curve at Q, and T, the points of contact with the rays RR, may be

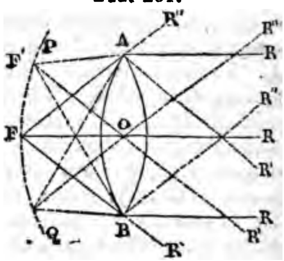
FIG. 200.



found by the means which [25] enabled us to trace the rays of light through a prism. For the path of R and R, must be such, that the ratio of the sines of the angles of incidence and refraction, will be the index of refraction for the given substance; and the point F—where lines, making these angles with the perpendiculars HP, BE, &c., intersect each other, after leaving the sphere—will be its principal focus, since R and R are supposed parallel.

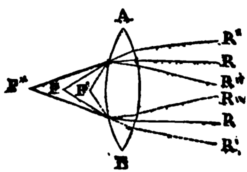
28. All the principal foci FF′F″ &c., fig. 201, are nearly equidistant from O, the centre of the lens—or that point, at which, the part of the axis, intercepted between the surfaces of the lens, is bisected: hence the image of an object is curved. If the centre ray of the pencil is coincident with the axis RF, the focus will be F: if coincident with R′F′, it will be F′: if coincident, with R″F″ it will be F″. Should the centre ray commence at any of the intermediate points, the focus will be found in some point of the curve F′FF″—which is not, however, exactly, the portion of a circle. Rays passing through the centre O, may be considered to suffer no refraction; as the equal and opposite refractions do not alter their directions.

Fig. 201.



29. Convergent rays R′R′, fig. 202, will come to a focus F′, nearer to the lens than F, the principal focus. If they are divergent, as R″R″, their focus F″ is farther off than F. The *radiant point*, or that from which they emanate, and the focus, to which they are concentrated, are called *conjugate foci*, and are interchangeable. Their distances, from the principal focus, at the side of the lens respectively next them, vary inversely: because the more the incident ray diverges, that is, the more the radiant point approaches the principal focus, the farther the emergent ray will travel, before it can *intersect* a ray passing through the centre of the lens:—

Fig. 202.

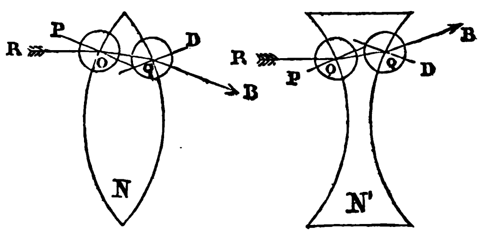


because the incident and emergent rays must make the same angle, as one of the parallel rays [27] makes with its corresponding emergent ray.

If the radiant point is at a distance from the lens, equal to twice its focal length, the focus of the rays emanating from it, will be at the same distance, on the other side of the lens.

30. The focus of a lens may be found, practically, as follows :—Let the lens be either N, or N′, fig. 203; and let RB be the ray. Mark on circles, described with centres O, O, arcs which will measure the angles of incidence and refraction, at the first surface; and, on circles, described with centres Q, Q, arcs which will measure the angles of incidence and refraction at the second surface :—then trace the ray through the points taken in these circles: and, through the centre of the lens, draw a line parallel to the first direction of the ray. The point where this line intersects the direction of the ray, after, or before it has passed the lens, will be the required focus.

FIG. 203.



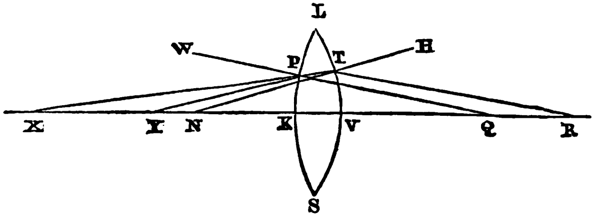
31. We may find the principal focus, also, by ascertaining the distance of the smallest point to which the lens will concentrate the sun's rays—which are considered as parallel, on account of the great distance of that luminary.

32. The focus of any kind of lens, for either parallel, converging, or diverging rays, may be ascertained by a general method, founded on principles given by Halley [Phil. Trans. 1693].*

* Let m, and n, be the sines of the angles of incidence, and refraction, when a ray passes from the atmosphere to a lens :—then $m:n$ will be [11] the ratio of the sines—or, of the angles themselves, as they are very small. Let LS, fig. 204, be a given lens; and let NT (=NV), be the radius of curvature of one of its surfaces. Produce NT to H. Let QP (=QK) be the radius of curvature of the other surface. Produce QP to W. Let R be any radiant

33. Since the conjugate foci are interchangeable, and it is immaterial from which extremity of it we consider the point:—to find YK, the distance of the other conjugate focus from the lens. Let the point T, be very near the axis; let RT, be a ray

FIG. 204.



from R; and let the first refraction be in the direction of TP. Produce TP to X.

In the triangle RTN, RN : RT : : sin. RTN (=sin. RTH, the angle of incidence, or m) : sin. TNR. But when angles are very small, they may be considered as proportional to their sines: therefore RN : RT : : m : TNR. But RN=RV+VN; and RT=RV (because T is very near V). Hence, substituting these, we have

$$RV+VN : RV :: m : TNR=\frac{RV\times m}{RV+VN}$$

But the angle TXY=TNR−XTN=TNR−n (since XTN is the angle of refraction)=(their equals)

$$\frac{RV\times m}{RV+VN}-n=\frac{RV\times m-RV\times n-VN\times n}{RV+VN}.$$

In the triangle NTX, NT : XT (=XV; because T and V, are supposed very near): : sin. TXY : sin. TNX=sin. TNR, its supplement;—or, (since they are very small) as the angles themselves; or, finally, as (their equals just found) $\frac{RV\times m-RV\times n-VN\times n}{RV+VN}$: $\frac{RV\times m}{RV+VN}$. Therefore XT (or its equal, XV)$=\frac{RV\times m\times NT}{RV+VN}\div$

$$\frac{RV\times m-RV\times n-VN\times}{RV+VN}=\frac{RV\times m\times NT}{(m-n)\times RV-VN\times n}.$$

To find YK, put XV−KV=d. In the triangle XPQ, XQ (=XK+KQ=d+QP) : XP (=d; because TV is very small) : : sin. XPQ (=sin TPQ) : sin. PQX : : (because the angles are very small) XPQ (the angle of incidence n. For, since the ray, in this case, passes from the lens to the air, the angle of incidence is *less* than that of refraction) : PQX. And substituting equal quantities

$$d+QP : d :: n : PQX=\frac{d\times n}{d+QP}$$

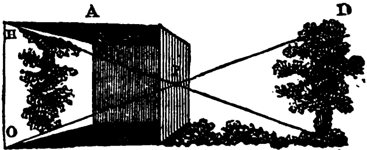
In the triangle QPY, the angle PYQ=WPY−PQX=m (the

ray to begin its motion, rays will not come to a focus, with a lens, if the radiant point is at an equal or less distance from the lens, than the principal focus.

34. *The burning glass*, is merely a convex lens, which concentrates the rays to a focus—at which point the heat is increased in proportion as the space which the concentrated rays cover, is less than the surface of the lens.

35. IMAGES FORMED BY LENSES.—If a small aperture P, fig. 205, is made in a window shutter, &c., an inverted image of the object DE, will be thrown on a wall HO, intended to receive it—the rays which would confuse the image being excluded. If a lens is placed in the aperture, it will render the image brighter, by collecting rays which must otherwise have escaped. Aristotle remarked that, whatever the shape of such an aperture, the image of the sun, formed by it, is always circular:—but the fact was not explained, until many centuries after. It is due to an

FIG. 205.



angle of refraction being now the *greater*) $-$ PQX $=m-$ (the equal of PQX, just found) $\frac{d\times n}{d+\text{QP}}=\frac{(m-n)\times d+\text{QP}\times m}{d+\text{QP}}$. And QP : YP (=YK; because the point P, is very near K) : : PYQ : PQX : : (their equals, just found) $\frac{(m-n)\times d+\text{QP}\times m}{d+\text{QP}}:\frac{d\times n}{d+\text{QP}}$. Therefore YP (or YK, the distance of the focus from the lens) $=\frac{d\times n\times \text{Q}}{d+\text{QP}}\div\frac{(m-n)\times d+\text{QP}\times m}{d+\text{QP}}=\frac{\text{QP}\times d\times n}{(m-n)\times d+\text{QP}\times m}$.

We may substitute, for d, its value

$$\text{XV}-\text{KV}=\frac{\text{RV}\times m\text{NT}}{(m-n)\times\text{RV}-\text{VN}\times n}-\text{KV}.$$

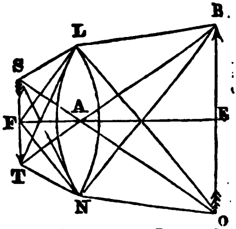
and we shall have the focus of double convex lenses, for divergent rays. If the thickness of the lens is inconsiderable, it may be neglected. If the rays are converging, RV, will be negative; if the rays are parallel, it will be infinite. If either surface is concave, the radius of that surface will be negative; if both are concave, the radii of both will be negative. If either is a plane surface, the radius of that surface will be infinite.

If any one term of this equation is unknown, it can of course be found.

infinite number of images, each the same shape as the aperture, being produced by all parts of the sun, and superimposed. These, when seen together, must—since the sun is circular—form a circular surface.

36. The use of a lens LN, fig. 206, in the aperture cannot cause the image to be confused; since rays from the various parts of the object BO, cannot interfere with each other. The nearer the object to the focus of the lens, the larger will be the image ST; for the angle under which it is seen is increased, which—as we shall see presently—increases the size of the image. Pencils of rays emanate from each point in the object; and each pencil is concentrated to a corresponding conjugate focus [29]. The image and object are to each other as their distances from the lens. If the object is in the principal focus, no image will be formed, since the rays will emerge parallel, and will not come to foci.

FIG. 206.



37. The farther the image is from the lens, the larger it is; because the more divergent the pencils become, before the rays of which they consist, come to their respective foci. If the image is farther from the lens than the object, it is larger than the object, and *vice versa*. The nearer the object is to the principal focus, the larger its image; because the rays emerge more nearly parallel—and, consequently, are the longer without coming to foci. A single lens gives an inverted image.

38. The image, formed by a lens, may be thrown on a screen of linen, muffed glass, &c. Persons have been frightened, by images formed with the magic lantern, being thrown on a fog—which acted like a screen.

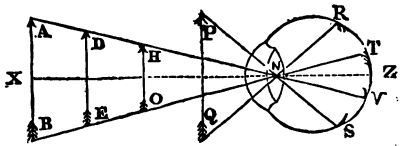
Rays will emerge from the image in a focus, as from a new object; and may, with reference to lenses, &c., be treated as such.

39. A lens seems to bring an object nearer, because it increases the angle under which it is seen—which would be effected also by bringing it nearer.

40. Fig. 207 shows how it is that the size of an image

is increased on account of the angle PNQ, which the object PQ=AB, subtends, being greater than the angle ANB, on account of PQ being nearer than AB to the lens N —supposed to be the crystalline humour of the eye. RS, the image formed by PQ, is larger than TV, which is formed by AB: and the image TV will evidently be produced, not only by AB, but also by the smaller objects DE and HO. We may intercept the view of the largest landscape with a sixpence, if we bring the latter sufficiently near:—since we may cause the image of the sixpence, within the eye, to be larger than that of the landscape. Increasing the angle of vision ANB, increases the image in the eye; because the pencils of rays from the object, become more divergent, before they come to foci within the eye. The apparent size of the object, is inversely proportional to its distance from the eye.

FIG. 207.



41. The apparent size of an object is magnified when, instead of the object itself, we view the image formed by a lens. For, if the object is 5,000 feet distant, and we use a lens of 5 feet focal length, the image will be to the object : : 5 : 5,000 [36]:—that is, it will be 1,000 times smaller. But, since this image may be considered as a new object [38], and may be viewed by the eye, not at the original distance of 5,000 feet, but at that of six inches, the smallest distance at which we can obtain distinct vision, the angle under which it is seen is greater; and [40] the image is as much larger, when seen at the distance of six inches, than when seen at the distance of 5,000 feet, as 5,000 feet is greater than six inches. The image, therefore, is, from this cause, magnified 10,000 times; and, since it was 1,000 times less than the object, it is equal to the object divided by 1,000, and multiplied by 10,000; and, consequently, it appears ten times as large as the object. If the length of the object is increased ten times, its entire surface is increased $10^2=100$ times.

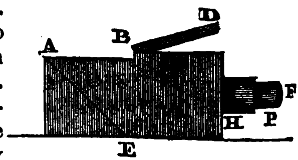
42. When the distance of the object is very great, com-

pared with the focal length of the lens, the magnifying power is equal to that length, divided by six inches, the smallest distance of distinct vision.

43. A lens, besides magnifying an object, increases its brightness, by intercepting rays which would otherwise escape. If this were not the case, the image would be as much less bright than the object, as its size is greater—the same number of rays being diffused over a larger surface.

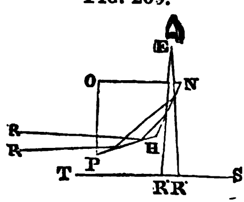
44. THE CAMERA OBSCURA,* invented by John Baptista Porta, is a box or chamber AEH, fig. 208, of any size. F is a lens, fixed opposite to the mirror AE—forming an angle of 45° with the horizon. The rays, from external objects, are transmitted by the lens; and being reflected by the mirror are received on the surface AB—supposed, in the present instance, to be muffed glass. This surface ought, strictly speaking, to be curved [28], that the foci corresponding to the different parts of the object may coincide with it: but a somewhat different arrangement would then be required. The construction of the Camera Obscura is only a development of the principle, which causes a picture of external objects to be produced on the opposite wall, by an aperture in the window-shutter, &c. [35]. This instrument assumes a variety of forms; it is, sometimes, a chamber sufficiently large to contain several persons.

FIG. 208.



45. THE CAMERA LUCIDA,† was invented by Dr. Wollaston. It depends on the fact, that the object is always referred by a spectator, to the place whence, on account of their *last* direction, the rays appear to have come. A landscape, &c., may seem to be a picture placed on a sheet of paper, provided the last direction of the rays by which it is seen, is from the paper to the eye of the observer. This is effected by a quad-

FIG. 209.

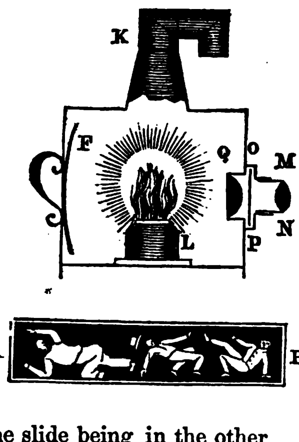


* Dark chamber. *Lat.* † Lighted chamber. *Lat.*

rangular prism of glass ONHP, fig. 209, of which the angle at O is 90°; that at N, 67·5°; that at H, 135°; and that at P, 67·5°. Rays RR, from some object will, after falling on one interior surface PH, be reflected by another, HN, to the eye at E; and, on account of their last direction, will seem to come from an object R′R′ on the paper, TS. If a perforated piece of metal is placed upon ON, so that only half of the aperture is over the angle N, both image and paper—apparently coincident—will be visible to an eye placed over the aperture: and the outlines of the object may be sketched with great accuracy, by a pencil, &c.

46. THE MAGIC LANTERN consists of a box, fig. 210, on the bottom of which is placed a lamp L, capable of sliding either towards OP, or in the opposite direction. A plano-convex lens, Q, fixed in the front, throws the rays, in a concentrated form, on the glass slide OP—represented also by AB—containing figures, &c., drawn with transparent paint. The rays, in passing through the slide, are coloured; and, being transmitted through a powerful lens MN, are thrown on a screen, which is in one of the conjugate foci, the slide being in the other. If the objects on the slides are alone visible, being surrounded by portions of the glass that have been rendered perfectly opaque, when the room is darkened, they will seem to a spectator placed behind the screen, like phantoms in the air: such representations are, on this account, sometimes called *phantasmagoria*.* The distance of the image, and therefore [37] its size, is altered by moving the lens MN, which, for this purpose, is made to slide in a tube attached

FIG. 210.



* *Phantasma*, a phantom; and ago, I bring. Gr.

to the lantern. The magnitude of the image is, however, limited by the illuminating power of the lamp, which is increased by the concave reflector F.

FIG. 211.

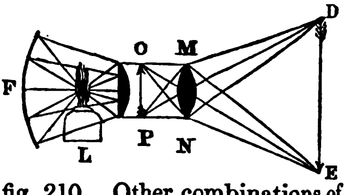
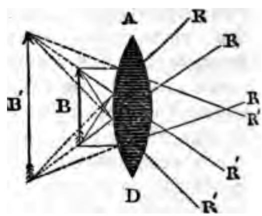


FIG. 211 represents the manner in which the rays form the image, on the screen DE. The letters correspond with those in fig. 210. Other combinations of lenses, also, are used.

47. *Dissolving views* are produced by two magic lanterns, fixed at the same focus, and so arranged that the light in each may be almost extinguished, at pleasure. When the picture is to be changed, the light of one lantern is brought, by degrees, almost to nothing, while that of the other is, in the same manner, increased to a maximum: by this means, one view fades away, and the other *gradually* becomes perfectly distinct.

48. MICROSCOPES.—THE SINGLE MICROSCOPE.*—Microscopes are instruments which, by giving an enlarged image of a minute object, enable us to see it more perfectly. They are either single or compound.

FIG. 212.



The single, termed also the *simple microscope*, consists merely of a lens AD, fig. 212. When an object is placed in the principal focus, the rays will emerge parallel; when at B, a little nearer to the lens, they will emerge with the same amount of divergence as if the object were placed at B′, the distance of distinct vision; and, on account of the visual angle being increased, it will appear as large as B′, instead of B—its apparent size, if it were at B′.

49. If the visual angle were increased, without a lens being used, the rays would enter the eye in such a state of divergence, that the power of adaptation possessed by that organ would not be capable of bringing them to foci on the

* *Mikros*, small; and *skopeo*, I examine narrowly. *Gr.*

membrane intended to receive the image. But, when the lens is interposed, the divergence of the rays is precisely what it would be, if the object were at the distance proper for distinct vision.

50. The magnifying power of a single microscope is found by "dividing the distance of distinct vision, by the focal length of the lens."*

EXAMPLE.--The focal length of a single microscope is $1\frac{1}{2}$ inches: what is its magnifying power?

The distance of distinct vision being six inches, $\frac{6}{1{\cdot}5}=4$ is the required magnifying power. The *surface* will be magnified $4^2=16$ times.

Watchmakers use a lens, of about one inch focus, set in a cell of horn which can be grasped by the muscles around the orbit of the eye.

51. A very small globule of glass—formed by melting the end of a fine thread of that substance in the flame of a candle, or by taking a little powdered glass on the point of a very small needle and melting it into a globule—will be found a powerful simple microscope. Such were the instruments, with which Lewenhoeck made all his discoveries.

52. Single microscopes do not, necessarily, consist of a single lens: there may be any number, provided that, taken together, they produce the effect of only one. Two lenses form what is called a *doublet;* three, a *triplet:* so many as seven have been used.

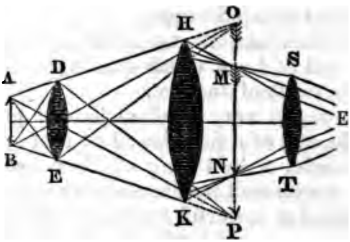
53. THE COMPOUND MICROSCOPE differs from the single, in having the image, formed by one lens called the

* For, as the apparent size of the object is inversely proportioned to its distance from the eye [40], its apparent size at B′, fig. 212, is to its apparent size B, as its distance from the centre of the lens in the latter case (which may be called *d*) is to its distance in the former (which may be called *d′*). Therefore, its apparent size at B′ is equal to its apparent size at $B\times\frac{d'}{d}$. But *d′*, is the distance of distinct vision: and *d*, is the focal distance. The point where the axis of the pencils from the object intersect each other, is supposed to be the *centre* of the lens:—which is not the case; since it is in the eye, behind the lens. The latter is, however, so near the eye, and its thickness is so small, that the error is inconsiderable.

object-glass, magnified by another, termed the *eye-glass*. It is not necessary, however, that there should be but two lenses: there may be any number, provided the effect of but two is produced. The eye-glass acts, with reference to the image formed by the object-glass, in the same way as the single microscope, with reference to the object itself.

54. *The field-glass* is a lens interposed between the object-glass and the eye-glass, to increase the "field of view:" that is, to render more of the object visible at once. Without it, only a small portion of AB, fig. 213, could be seen, unless by changing its position, and bringing different parts of it successively into view. For, the rays, from its extremities, would, after passing through the object-glass DE, diverge to O and P, so that they could not pass through the eye-glass ST—nor, by consequence, ever reach the eye. But, being deflected by the field-glass HK, they come to foci at M and N, and after passing through ST enter the eye.

FIG. 213.



55. The magnifying power of a compound microscope is found "by multiplying together the magnifying powers of the object and eye-glasses." Thus, if an image produced by the object-glass is six times greater than the object, and this image is magnified ten times by the eye-glass—because seen at one-tenth of the distance of distinct vision [50], the microscope increases the apparent size of any dimension of the object sixty times.

56. *The oxy-hydrogen microscope.*—It has been already remarked [43] that, when the apparent size of any thing is increased, the quantity of light must be augmented to at least an equal extent. This object was frequently obtained, by causing the rays of the sun to pass through whatever was to be examined. But such a mode of illumination was attended with several inconveniences: among others, a *cloudless* sky cannot always be had; and the sun's ap-

parent motion renders it necessary that the mirror which throws the light on what is being magnified, should have its position continually changed. The great brilliancy of the oxy-hydrogen lime-light, soon suggested it as a substitute for the solar rays; and the oxy-hydrogen microscope has almost entirely superseded the solar.

57. The magic lantern and oxy-hydrogen microscope are very similar in principle, but the objects used are different; as, also, the size, and number of lenses, &c.

58. In consequence of their high refractive power, lenses formed of the diamond, and other precious stones, have been used in microscopes. A diamond lens, having the same magnifying power as one of glass, requires to be only one-third as thick. The diamond lens may, therefore, be made of greater diameter: this allows a greater quantity of light to enter the eye. However, the property of double refraction—which, as we shall see, produces a double image—the colour, and the heterogeneous structure of precious stones, have been found to more than counterbalance the advantages obtained from them. The attempt to employ fluid lenses, or to give glass other shapes than the spherical, have been equally unsuccessful.

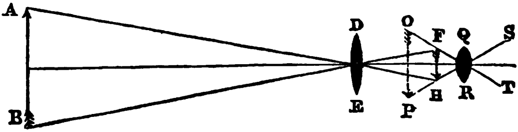
59. Refracting Telescopes.—The Astronomical Telescope.—The principle on which the telescope depends,* is said to have been discovered by an accident, which has been variously related; and the result of which, at the time it happened, was not understood. The first telescope is supposed to have been made by John Baptista Porta, towards the end of the sixteenth century.

60. The simplest form of astronomical telescope consists of a double convex lens, placed at one end of a tube, six inches longer than the focal length of the lens. An image is formed, in the air, within the tube, six inches from the end where the eye is placed: and is seen as a new object [38].

61. The effect of such an instrument is easily found, from what has been already said [41]. Its power is still farther increased, by placing, at the extremity of the tube next the eye, a lens QR, fig. 214, the focus of which coincides with the focus of the object-glass. This eye-glass in-

* *Tēle*, afar off; and *skopeo*, I observe narrowly. Gr.

Fig. 214.



creases the apparent size of the object A B, by magnifying the image FH, produced by the object-glass DE. It is evident that there is a close resemblance between this telescope, and the compound microscope: the chief difference between them being, that the image produced by the object-glass of the microscope is larger, while that produced by the object-glass of the telescope is smaller than the object—since it is formed [36] at a much less distance from the object-glass, than the place occupied by the object.

62. The magnifying power of this telescope, is obtained by dividing the focal length of the object-glass, by the focal length of the eye-glass.*

Example.—The focal length of the object-glass is 3 feet, and that of the eye-glass 1·04 inches: what is the magnifying power? $\frac{3 \text{ feet}}{1{\cdot}04 \text{ inches.}} = 34{\cdot}61$ nearly.

63. Another lens is added, to render the image erect—and thus accommodate this telescope to terrestrial objects; also, one to make the rays parallel, as they enter the eye—for that organ always sees distinctly, when the rays which enter it are parallel. These glasses, however, do not

* For, calling the centre of the object-glass DE, fig. 214, C; the centre of the eye-glass QR, V; and the central point of FH, N: the angle under which the object AB would be seen by a naked eye, if placed at C, is ACB=FCH. But the angle, under which the image is seen, is FVH. And, since [40] the apparent size of the same object, is inversely as its distance from the eye, FVH : FCH :: CN : NV. Therefore, $FVH = \frac{FCH \times CN}{NV}$:—that is, any dimension of the object, as seen with the telescope, is equal the same dimension, as seen with the naked eye, multiplied by $\frac{CN}{NV}$. Therefore, $\frac{CN}{NV}$ is the magnifying power of the telescope. *But CN is the* focal length of the object-glass: and NV, that of *the eye-glass.* The sum of both is the length of the telescope.

affect the magnifying power of the instrument. Although the rays belonging to the pencils from the different parts of the object, or image, emerge parallel, the divergence of the axes of these pencils—or the visual angle—is not affected.

64. The different distances of objects, require corresponding alterations of the focus of the object-glass [29]. When, therefore, the object is nearer, the eye-tube must be drawn out: and when farther, pushed in. Dr. Brewster applied this fact to the measurement of distances: the sliding tube of the telescope being graduated for the purpose. "The distance of the object minus the principal focus of the object-glass, is equal to the square of the focus of the object-glass, divided by the increase of the length of its focus,"*

EXAMPLE.—The focus of an object-glass is 3 feet; and the increase of its focal length is 0·00902 of a foot. The distance of the object, therefore, is $\frac{3^2}{0{\cdot}00902}+3=\frac{9}{0{\cdot}00902}+3=997\dot{1}\frac{1}{2}+3=1{,}000\frac{1}{2}$ feet.

65. CATOPTRICS,† comprehends the laws which govern *reflected* light. When light is refracted, some of it is lost by reflection. The mirrors which are used to reflect light, are either *plane*, *concave*, or *convex*; and they consist of glass covered with an amalgam of mercury, or of metal. When the mirror is of glass, most of the rays are reflected from the silvering, after being refracted by the glass. When light falls very obliquely, it is better reflected by glass, than by metal. The *plane of reflection*, is a plane passing through the incident and reflected rays.

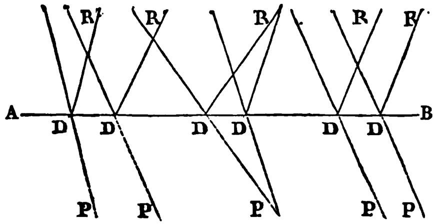
66. If parallel, converging, or diverging rays R, R, &c., fig. 215, are thrown on a plane mirror AB, they will be

* Let F, be the distance of a focus from the principal focus, and also that of the conjugate foci [29], when they are equidistant. Let d be any other distance from the principal focus; and let a be the distance of the corresponding conjugate focus. Since [29] the distances of the conjugate foci from the principal focus are inversely proportional, $F:d::a:F$, and $d=\frac{F^2}{a}$. The whole distance of the radiant point from the lens is $\frac{F^2}{a}$ the distance of the principal focus.

† *Kata*, against; and *opto*, I see. *Gr.*

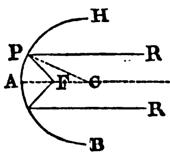
reflected at the points D, D, &c., and will seem to come from points P, P, &c., behind the mirror. Neither their parallelism, nor the angle of their convergence, or divergence, will be altered by reflection:—otherwise, as is evident from the figure, the angles of incidence and reflection would not be equal.

FIG. 215.



67. FOCI OF MIRRORS.—*A concave spherical mirror*, HAB, fig. 216, will reflect rays RR—supposed parallel to, and almost coincident with, AD the axis of HAB—to a focus, which will be at a distance from the mirror, very nearly equal to half its radius of curvature.*

FIG. 216.



68. The farther the rays are from DA, the nearer the focus to the mirror:† those which are very near, are called *central* rays. If the axis of the mirror is turned towards the sun, the focus to which its rays are concentrated, may be considered as the principal focus—since, on account of the distance of that luminary, its rays may be looked upon as parallel. And we may ascertain the radius of curvature of the mirror, by doubling its distance from the principal focus thus found.

69. The focus of *convergent* rays, will evidently be nearer to the mirror than the principal focus: and its dis-

* For, C being the centre of curvature, draw CP. The radius is perpendicular to the curve at the point of contact; and, since the angles of incidence and reflection are equal, CPR=CPF. But, since DA and RP are parallel, CPR=PCF:—hence CPF=PCF; and FC=FP (because opposite to the equal angles). But, when RP is very near DA, FP (and therefore, FC) may be considered=FA: and, when FA=FC, $FA=\frac{CA}{2}=\frac{\text{Radius}}{2}$.

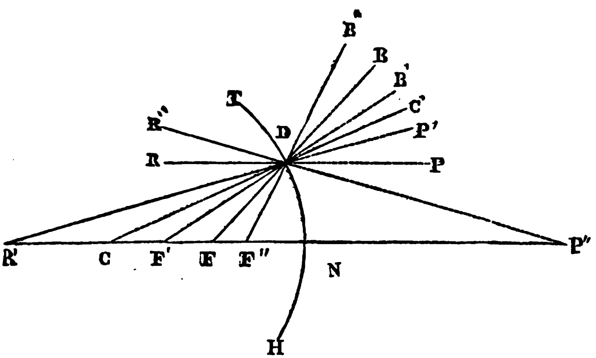
† *It is* evident that, as the distance between DA, and RP, fig. *216, increases*, the point F moves nearer to the mirror.

tance from the latter, will be equal to "the square of half the radius of curvature, divided by the distance of the point of convergence from the principal focus."*

70. The distances of the conjugate foci from the principal focus, vary inversely. Thus, if the distance of P' from F is doubled, the distance of F'' from F will be diminished to one-half.†

* Let C, fig. 217, be the centre of curvature of the concave mirror TH. Let RD be very near, and parallel to the ray coincident with the axis $R'P''$: and let F be the principal focus. Let the rays be $R''D$ and $R'N$:—P'' is their point of convergence: and F'', is their focus. The triangles $P''DF$ and $DF''F$ are similar, since they have a common angle at F; and the angles $DP''F$ and FDF'' are equal, being each of them equal to $R''DR$. For $DP''F = R''DR$, because RD and $R'P''$ are parallel; $FDF'' = R''DR$, because, since $R''DC$ (the angle of incidence) $=CDF''$ (the angle

FIG. 217.



of reflection), and RDC (the angle of incidence) $=$ CDF (the angle of reflection), $R''DC - RDC$ $(R''DR) = CDF'' - CDF$ (FDF''). Hence,

$$FP'' : FD :: FD : FF''.$$

But, since RD is supposed very near $R'P''$, FD [67 : note] may be considered $=FN=\frac{\text{Radius}}{2}$. Therefore $FP'' : \frac{\text{Rad.}}{2} :: \frac{\text{Rad.}}{2} : FF'' = \left(\frac{\text{Rad.}}{2}\right)^2 \div FP''$.

† Since [69 : note], $FF'' = \left(\frac{\text{Rad.}}{2}\right)^2 \div FP''$, as $\left(\frac{\text{Rad.}}{2}\right)$ is constant, with a given mirror, FF'' varies inversely as FP''.

71. When the rays become parallel, P″ becomes infinitely distant: and, the divisor FP″ having become infinitely great, the quotient—that is, the distance FF″—will become 0; F and F″ will then coincide.

72. Since the path of a ray is the same, from whichever extremity of the line representing it we suppose it to begin its motion [33], when the luminous point is at F″, the other conjugate focus will be at P″, and *imaginary.*

73. The focus of *divergent* rays, will be farther from the mirror than F the principal focus: and its distance from the latter, will be equal to "the square of half the radius of curvature, divided by the distance of the point of divergence from the principal focus."*

74. The distances of the conjugate foci from the principal focus, in this case also, vary inversely.† When the luminous point is in C the centre of curvature, the focus, to which the rays converge will be at C, twice the focal distance from the mirror [29].‡

75. Since the path of a ray is the same, from whichever

* Let the rays be R′D, R′N, fig. 217:—R′ is their point of divergence; and F′ is their focus. The triangles R′DF and F′DF are similar: since they have a common angle at F; and the angles DR′F and F′DF are equal, being each of them equal to RDR′. For DR′F=R′DR, because RD and R′P″ are parallel; F′DF=RDR′, because, since RDC (the angle of incidence)=CDF (the angle of reflection), and R′DC (the angle of incidence)=CDF′ (the angle of reflection) RDC−R′DC (RDR′)=CDF−CDF′ (F′DF). Hence,

$$R'F : FD :: FD : FF'.$$

$$\text{But } FD \ [69:\text{note}] = \frac{CN}{2} = \frac{\text{Radius}}{2}.$$

$$\text{Therefore } R'F : \frac{\text{Rad.}}{2} :: \frac{\text{Rad.}}{2} : FF' = \left(\frac{\text{Rad.}}{2}\right)^2 \div R'F.$$

† Since, [73 : note], $FF' = \left(\frac{\text{Rad.}}{2}\right)^2 \div R'F$, as $\left(\frac{\text{Rad.}}{2}\right)^2$ is constant, with a given mirror, FF′ varies inversely as R′F.

‡ For, since, in this case, R′F, fig. 217, $= \frac{\text{Radius}}{2}$, the value of FF′ [73: note] will become $\left(\frac{\text{Rad.}}{2}\right)^2 \div \frac{\text{Rad.}}{2} = \frac{\text{Rad.}}{2} \times \frac{\text{Rad.}}{2} \div \frac{\text{Rad.}}{2} \times \frac{\text{Rad.}}{2} = CF$. The latter will, therefore, be the distance of F′ from *F; and,* consequently, F′ will be at C.

extremity of the line representing it, we suppose it to have begun to move [33], if the luminous point is in either of the conjugate foci, the rays will come to a focus in the other.

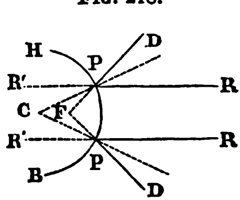
76. Concave mirrors, are sometimes used to bring the sun's rays to a focus; and thus to produce the same effect as the burning glass [34]. Some of the mirrors employed for this purpose have been very powerful:—that of M. De Vilette was 3 feet 11 inches in diameter, and its focal distance was 3 feet 2 inches; it was formed of tin and copper. A silver sixpence placed in its focus, melted in 7½ seconds; and a copper halfpenny in 16 seconds.

77. Burning mirrors are sometimes made with a number of plane mirrors, arranged so as to form a kind of curved surface. Count Buffon constructed one of 168 small mirrors, each 6 inches square; and, by means of it, with the feeble rays of the sun in the month of March, set fire to beech-wood, at the distance of 150 feet; and fused silver at the distance of 50 feet. Archimedes, about 200 years BC., burned, with mirrors, the ships of the Romans, who were besieging Syracuse: and, in the same way, Proclus destroyed the fleet of Vitellius, at the siege of Byzantium. It was remarked, by the members of the Academy del Cimento, that the most powerful mirrors will not set fire to alcohol, or other inflammable liquors.

78. The intensity of the heat produced by a burning mirror, is equal to the area of the reflecting surface, divided by the area of the small circle of light in the focus—any loss that occurs not being taken into account.

79. *Convex Mirrors*, have only an "imaginary" focus. Thus, parallel rays RR, fig. 218, will be reflected to D, D: and will seem to come from F, which would be the focus of parallel rays R′R′, if the mirror were concave.

FIG. 218.



80. Parallel rays being represented by the lines PD, and P″N, fig. 217, and the convex mirror by TH, PD will be reflected to B, and P″N back to P″: and, if produced, they will intersect each other behind the mirror at F—the principal focus of parallel rays, when the mirror is concave. F, therefore, is

a *real* focus, when the mirror is concave; but *imaginary*, when it is convex.

81. If converging rays are represented by the lines P′D and P″N, fig. 217, they will be reflected, respectively, to B′ and P″; and the lines of reflection would, if produced, intersect each other at F′—the focus of diverging rays, the mirror being concave. F′, therefore, is a *real* focus, when the mirror is concave: but an *imaginary*, when it is convex. If the convergence of the rays, or the curvature of the mirror, were diminished, the focus might be more distant, or the reflected rays might become parallel—so as never to meet, and produce even an imaginary focus.

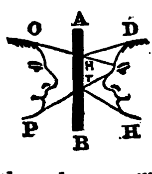
82. If diverging rays are represented by P″D and P″N, fig. 217, they will be reflected, respectively, to B″ and P″: and, if the lines of reflection are produced, they will intersect each other at F″—the focus of converging rays, if the mirror were concave. F″, therefore, is an *imaginary* focus, when the mirror is convex, but a *real*, when it is concave.

83. The manner of determining the position of these foci, or of others corresponding to rays having any given direction, may easily be found from what has been said [69, &c.].

84. When the surface on which rays of light fall is convex, it is evident that each portion of the surface, oblique to the luminous body, receives fewer rays than an equal portion, directly opposite to it. And the quantity diminishes, as a tangent to the surface approaches to parallelism with the direction of the rays. This is one reason why, although the earth is nearer to the sun in winter than in summer, the light and heat it receives in the former, is less than what it receives in the latter season.

85. Images formed by Mirrors.—A *plane* mirror, AB, fig. 219, causes the object DH to appear at a side of the mirror different from that at which it really is. For, when the rays enter the eye, they seem to come from OP, an object at the other side of AB: and, therefore, [45] they are referred to OP. When a person views himself in a looking-glass AB, whatever his distance from the latter, the size of his image on the glass, will

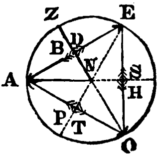
Fig. 219.



always be found equal to half his real size. For, HT, the section of the rays proceeding from his image to his eye, will always be equal to $\frac{OP}{2}$ or $\frac{DH}{2}$: since the object and image are at equal distances from AB.

86. If an object AB, fig. 220, is placed between two mirrors, AN and NZ, inclined to one another at an angle of 60°, several images will appear, arranged in the circumference of a circle. For, the image of AB, in AN, is AP; and its image, in NZ, is DE; the image of AP, in NZ, will be ES; the image of DE, in AN, will be TO: OH is the image of TO, in NZ, and also of ES in AN—but these two images will not coincide, if the angle ANZ is more or less than 60°.

FIG. 220.



87. The *Kaleidoscope*,* is an instrument founded on this multiplication of images by mirrors forming an angle. It was invented by Dr. Brewster, and was proposed by him as a means of creating beautiful forms. The mirrors are to be placed at any angle which is an aliquot part of 360°. They are generally fixed in a tube, at one end of which are fragments of coloured glass, &c., lying between two parallel plates of colourless glass: the surfaces of the latter are perpendicular to the line of intersection of the mirrors: and the outer one is muffed, to render the light uniform. On looking down the tube, through a small aperture, near the meeting of the mirrors, and at the extremity opposite to that where the coloured glass, &c., is placed, a beautiful symmetrical figure will be seen, which will be varied every time the position of the coloured glass is changed, by slightly shaking the kaleidoscope.

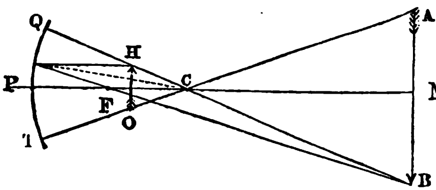
This instrument has been made to produce combinations of flowers, trees, &c., by forming inside of it, with a lens, images of distant objects.

88. When the mirror QT, fig. 221, is *concave*, an object HO, lying between C, the centre of curvature, and F, the principal focus, will form an inverted and enlarged image AB. For, let HQ, and HE be rays coming from H, some

* *Kalos*, beautiful; *eidos*, appearance; and *skopeo*, I observe narrowly. *Gr.*

point in the object—the former in the same direction as the radius CQ. Let the angles HEC and BEC be equal. HQ, since it falls perpendicularly on the curve, will be reflected along QB, HE,

FIG. 221.



will be reflected along EB, and will intersect QB in some point B:—thus, rays from H will form an image of that point, at B. In the same way, an image of O will be formed at A; and images of each point in HO, at corresponding points of AB.

89. If AB is an object placed beyond C, the centre of curvature, an inverted and diminished image HO, will be formed between C and the principal focus. Because, if the luminous point is in either conjugate focus, the rays emanating from it will [75] converge to the other.

90. The relative position of the image and object, may be determined from what has been already said [73]. Their relative sizes will be as the squares [41] of their distances from the centre of the mirror.*

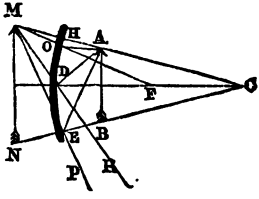
91. A person standing in front of a concave mirror, and a little farther from it than its centre, will see an inverted image of himself in the air, which will advance, recede, stretch out the hand, &c., according to his own movements. A large concave mirror, concealed from view, has been used in public exhibitions to produce singular deceptions. A person standing on his head in one conjugate focus, was seen by the spectators erect in the air, at the other. When any one attempted to take fruit, &c., from the hand of the image—which appeared a real person—a dagger was suddenly and dexterously presented in its place. The image, formed by a concave mirror, may be thrown on a screen, on the smoke from a chafing dish placed underneath, &c.

92. When the object AB, fig. 222, is between the *con-*

* For, Z being a point intermediate between H and O, AB : HO :: NC : CZ. But their surfaces [41] are as $AB^2 : HO^2$, that is, as $NC^2 : CZ^2$.

cave mirror HE and its principal focus F, the rays appear to come from an erect and magnified image behind the mirror. For, let AH, fig. 222, be a ray from A, perpendicular to the mirror: it will be reflected back in the direction HC. Let AO be a ray parallel to the axis CD: it will be reflected [67] to F, the principal focus. If HC and OF are produced backwards, they will intersect each other at M—as will all rays DR, EP, &c., coming from A: they will, therefore, be referred to M. In the same way those coming from B, will be referred to N; and those, from every other point of AB, to corresponding points of MN. They will, therefore, be referred to an enlarged image MN, behind the mirror HE.

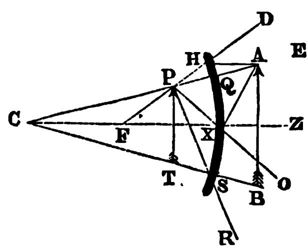
FIG. 222.



93. The nearer the object is to the mirror, the less the image:—when the object touches the mirror, its image is equal to it in size. The latter may be easily determined.

94. If the mirror HS, fig. 223 is *convex*, rays from an object AB will seem to come from a diminished and direct image behind it. Let AQ be a ray perpendicular to the curve HS: it will be reflected back in the direction QA. Let AH be a ray parallel to the axis CX, F being the principal focus, it will be reflected in the direction HD [79]. If QA and HD are produced backwards, they will intersect each other at the point P—as will all rays XO, SR, &c., coming from A: they will, therefore, be referred to that point. In the same way, the rays coming from B will be referred to T; and the rays from all the points between A and B, to corresponding points in PT. They will, by consequence, seem to come from an image PT, behind HS.

FIG. 223.



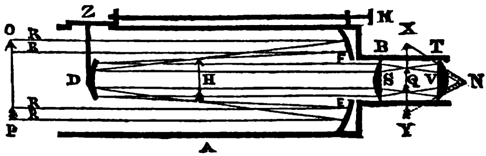
The relative positions of AB and PT, may be determined from what has been already said [69]. And their relative

sizes are as the squares [41] of their distances from C, the centre of the mirror.

95. THE REFLECTING MICROSCOPE.—If HO, fig. 221, is a very small object, an image of it will be formed at AB, which may be viewed with the naked eye—or, what is better, with a convex lens. Such an arrangement, would constitute a "reflecting microscope."

96. REFLECTING TELESCOPES. — THE GREGORIAN TELESCOPE consists of a large concave mirror EF, fig. 224, containing an aperture in the middle and placed within a

FIG. 224.



tube AZ. A smaller concave mirror D, is fixed in the axis of the larger, and at a distance from it, equal to a little more than the sum of their focal lengths. The smaller tube T, contains the field glass B—which is a plano-convex lens, and the eye lens T. An image of the distant object OP, is formed a little farther [73] from EF than its principal focus. When this image is in the principal focus of D, the rays from it will be reflected parallel [72]. But, when it is a little farther from D than its principal focus, they will cross each other, and passing through the aperture in the larger mirror, will form a direct image at Q. Without the field glass S, which brings the rays more quickly to a focus, this image would have been at a greater distance from D, and many of the rays [54] would never have reached the eye. The image is magnified by the lens T.

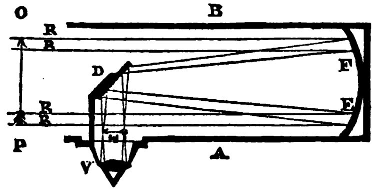
A screw M is so arranged that, by means of it, the smaller mirror is moved along the axis of the larger—to accommodate the instrument to objects at different distances [74].

97. THE CASSEGRAINIAN TELESCOPE, has a small convex, instead of concave mirror, at D, fig. 224; it is placed *at a distance* from the larger mirror, equal to the difference

of their focal lengths. In this telescope, only one image is formed—that at the eye-glass.

98. THE NEWTONIAN TELESCOPE, consists of a large concave mirror, EF, fig. 225, fixed in a tube AB: of a plane speculum D, inclined to the axis of the tube at an angle of 45°; and of a tube, containing an eye-piece V. An image of the distant object OP, would be formed by the mirror EF, in some place behind D: but the rays being reflected, it is formed at H, and is magnified by the lens V.

FIG. 225.



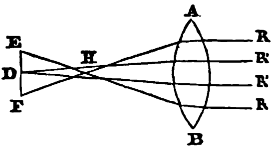
99. The reflector D, and the eye-piece V, are moved along the great tube—so as to adjust the instrument for objects at different distances [74].

100. Images formed by refraction, are more or less indistinct, on account of the production of colours—for reasons to be explained hereafter: those produced by reflection, are free from this inconvenience. Also, a lens having the same focal length as a mirror, must have a greater curvature. The focal length of a plano-convex lens, for instance, is twice the radius, while that of a concave reflector is but half the radius:—when, therefore, their focal lengths are equal, the curvature of the lens is four times as great as that of the mirror.

101. Sir D. Brewster gives the following method of finding the magnifying power of any telescope:—"Having put up a circle of paper, an inch or two in diameter, at the distance of about 100 yards, draw upon a card two black parallel lines, whose distance from each other is equal to the paper circle. Then, through the telescope, view the circle with one eye, and the parallel lines with the other; and at the same time, let the parallel lines be moved nearer to, or farther from the eye, till they seem exactly to cover the circle. The quotient obtained by dividing the distance of the paper circle by the distance of the parallel lines from the eye, will be the magnifying power of the telescope."

102. SPHERICAL ABERRATION.—We have supposed that, when lenses or mirrors are used, all the rays meet at the focus:—this, however, is not the fact. The distance between the farthest and nearest points D, and H, fig. 226, at which the rays intersect each other is called the *longitudinal aberration;* and EF, the distance to which the rays RR have diverged before R′R have come to a focus, is called the *lateral aberration.* The term "spherical aberration" is used, because it arises from the sphericity of the lens, &c.

FIG. 226.



103. We may illustrate spherical aberration, by covering first the centre, and then the circumference of a lens:—we shall find that the focus obtained in the former, will not be the same as that obtained in the latter case.

It is evident that, when a mirror is used, parallel rays R, R, fig. 216, cannot meet at one point F, except the lines representing the incident and reflected rays, make equal angles with perpendiculars to the curve—which will be the case only when the latter is a parabola [pneum. 100.] When the rays are divergent, they cannot come to the same focus, unless the mirror is part of a figure generated by the revolution of an ellipse on its major axis; and then, when the luminous point is in one focus, the rays will converge to the other [pneum. 101].

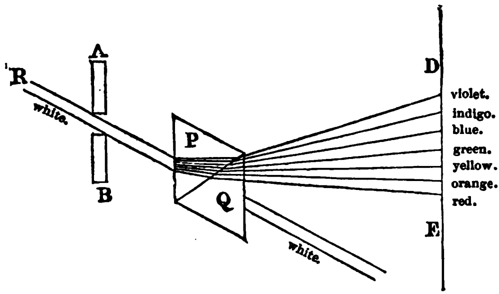
104. Since [100] a mirror having the same focal distance as a lens, is not nearly so spherical, it is not so much affected by spherical aberration.

105. CHROMATICS.*—We have hitherto supposed that light is capable of being resolved into elements: and, before Sir I. Newton discovered that white light is formed by a union of the different coloured rays, and devised a means of decomposing it, the production of the different colours was explained by most absurd suppositions. During his experiments, however, on the nature of light, Newton found that the different colours are not refracted to the same focus: and that the consequent production of coloured images, was one of the most serious obstacles to

* *Chrōma*, colour. Gr.

the perfection of the refracting telescope [100]. It must, at first sight, appear strange that white light should be a compound of all the colours: but this may be demonstrated both analytically, and synthetically, by experiment. If a ray R, fig. 227, passing through an aperture in a window

FIG. 227.



shutter AB, is thrown on a triangular prism P, it will form on a screen DE, placed to receive it, an oblong coloured image—the various tints of which the white ray was composed, being differently refracted, the violet most, and the red least. A second prism Q, exactly like P, will reunite all the coloured rays, and combine them again into a white one. The oblong image of the sun, formed on the screen, is called the *solar spectrum;* and, within certain limits, the smaller the aperture in the shutter, the brighter its colours will be. Seneca remarked the production of colours, when the sun's rays are made to pass through an angular piece of glass.

106. In reality, blue, red, and yellow are the only colours present, the rest being combinations of them. For the spectrum consists of a layer of each of these colours, superimposed on the others—the blue, the red, and the yellow appearing distinctly at those points, at which they are most vivid in the superimposed and corresponding layers.

107. Some white light is to be found along with the coloured, in every part of the spectrum;—for, at every part of it, there are the constituents of white light, plus an excess of the predominating colour. If we absorb this

excess, white light, which may be decomposed by absorption but not by refraction, will remain.

108. It can be proved synthetically, that white light is a combination of coloured rays, by dividing a circular card, with radii, into compartments of a size respectively proportioned to the extent of the different colours in the spectrum: and then putting in each division its proper tint. If the card is rapidly twirled round on its centre, it will appear nearly white: and would be perfectly so, if the arrangement of colours were absolutely correct.

109. The following are measures of the different colours of the spectrum, as made by Fraunhofer with a prism of flint glass, the entire spectrum being considered as divided into 360 parts.

Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
56	27	27	46	48	47	109

110. The following are the indices of refraction for the different colours, with crown, and flint glass:—

—	Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
Crown glass,	1·5258	1·5268	1·5296	1·5330	1·5360	1·5417	1·5466
Flint glass,	1·6277	1·6297	1·6350	1·6420	1·6483	1·6603	1·6711

111. The three colours, of which the spectrum [106] is really composed, are thus divided among the seven, which it contains: calling red rays R, yellow Y, and blue B.

White.	Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
20R.+30Y.+50B.	8 R.	7 R.+7 Y.	8 Y.	10 Y.+10 B.	6Y.+12 B.	12 B.	16 B.+5 R.

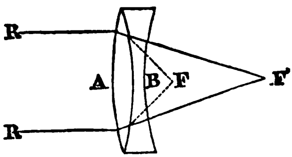
The coloured spaces of the spectrum do not always bear the same proportion to each other: this is called the "*irrationality*" of the spectrum.

112. Dark parallel lines are seen across the spectrum, when it is carefully examined: their number and position are different with light from different sources, or from the same source, but transmitted through different media. Thus, the vapour of iodine adds to their number; and gaseous nitrous acid makes them so numerous that, when the gas is heated, it becomes opaque, the spectrum being entirely obliterated. These lines show that rays of certain refrangibilities are absent. Altering the prism alters their position, but does not change their relative distances.

113. The violet rays are called the "most refrangible:" and the red, the "least refrangible rays." The angle made by the green ray, with the original direction of the decomposed white ray, is called the "mean refraction" of the prism. The extent to which the different rays of light are separated by a prism, is called its "dispersive power." With water, the index of refraction for the red rays is 1·330, and for the violet 1·344: the difference is, therefore, 0·014. With flint glass, the index of refraction for the red rays is 1·628, and for the violet 1·671: the difference is, therefore, 0·043. The dispersive power of flint glass is, by consequence, three times as great as that of water; and hence, it will produce a spectrum three times as broad. A substance may have a greater refractive, though not a greater dispersive power, than another. Thus, the mean refractive powers of flint and crown glass differ but little, while the dispersive power of the former is almost twice as great as that of the latter.

114. The knowledge of this fact enables us to produce combinations of lenses which are nearly *achromatic*.* The dispersion caused by the convex lens A, fig. 228, made of one kind of glass, is corrected by the concave lens B, made of another: and the curvature of the latter, though it diminishes, is not sufficiently great entirely to take away the convergency of the rays: for, while without B, their focus would be at F, when B is added, it is merely removed to F′.

FIG. 228.



* *A*, privative; and *chrōma*, colour. *Gr.*

115. Mirrors are attended [100] with the great advantage of having no dispersive power.

116. PROPERTIES OF THE SPECTRUM.—The spectrum, as we have seen, consists of seven colours reducible to three. In addition to these, it contains invisible rays, which are either *calorific*, or *chemical*, in their action. Scheele remarked that chloride of silver is blackened by the violet, but is not affected by the red, or the yellow rays. And Ritter of Jena, in 1801, observed that the chloride was blackened by invisible rays beyond the violet. Herschel noticed, that violet glass intercepts calorific rays.

117. The calorific rays increase from the violet to the red, but extend beyond the latter; the chemical increase from the red to the violet, and extend beyond the latter. The position of the calorific rays is different, with different prisms. When crown glass is used, they are, principally, in the middle of the red space; with a hollow prism containing sulphuric acid, they are in the orange; and with one containing oil of turpentine, or water, they are in the centre of the yellow space.

118. A principle has been discovered in light, which has been called *Actinism*,* and produces important changes in both the organic, and inorganic kingdoms. Its existence is proved from the fact that seeds will not germinate under the influence of rays transmitted through yellow glass—the *actinic* principle being intercepted. In spring, this principle is most abundant; in summer, the *luminous* principle is required for the formation of woody fibre: and towards autumn, the calorific or *ripening* principle.

119. It is not improbable that light and heat are modifications of the same thing: flame, when it first becomes visible, is violet: and it is white, only when the heat has become very intense. It is possible that the calorific rays are invisible, because our organs are imperfect, and not because they differ in their nature from those which are coloured: they may, like sounds, be imperceptible to some animals [pneum. 70], but appreciated by others. The chemical and calorific invisible rays are capable of reflection, refraction, and polarization.

120. The chemical action of light is very remarkable:

* *Aktin*, a sunbeam. *Gr.*

It bleaches, by causing the oxygen of the atmosphere to unite with the colouring matter. Nitric acid is decomposed by light. If equal volumes of hydrogen and chlorine are exposed to direct solar light, they combine, with explosion and the evolution of intense heat, just as occurs when the electric spark is passed through, or spongy platina, &c., is introduced into them. Prussian blue exposed to the direct rays of the sun, loses its oxygen, and becomes white; but regains oxygen and its colour, in the dark. Crystallization requires light. If a dish, half covered with paper, and containing the solution of a salt, is set aside to crystallize, but few crystals will form in the dark part, though there may be abundance of them in that which is not covered. Long exposure to light decomposes peroxide of mercury into metallic mercury and oxygen. But, among all the remarkable effects which are found to be produced by light, there is, perhaps, none which has led to such wonderful results as the blackening of some of the salts of silver by its action. This fact has given rise to photographic* or photogenic† drawing—

121. PHOTOGRAPHY.—It was known even to the ancient alchymists, that a substance, washed with the solution of a salt of silver, and then with a solution of common salt, would become black. If paper wetted with a solution of common salt or, which is better, bromide of potassium, and afterwards with a solution of almost any of the salts of silver, is held opposite to the lens of a camera obscura [44], or behind an engraving on paper, &c., and rays of light are transmitted through them for a sufficient length of time, by holding them against a pane of glass in a window, &c., the light will cause a proportionate darkness in the salt of silver; and the shadows will be expressed by the unaltered portions of the paper—what is called a "negative picture" being produced. If this could be used instead of the original engraving, &c., it would give a "positive;" but, unless the lights and shadows are fixed, exposing it to the light would have the effect only of blackening its entire surface, and completely obliterating the negative picture, before a positive one could be obtained.

* *Phōs*, light; and *grapho*, I write. *Gr.*
† *Phōs;* and *ginomai*, I produce. *Gr.*

122. Several persons, among others Wedgewood and Sir H. Davy, attempted to remove this difficulty; but without success, until Niepce and Daguerre* made their experiments. As a reward for their important discovery of a method for fixing the picture obtained by means of the camera obscura, the French Government gave to the former a pension of 4,000, and to the latter, of 6,000 francs, on condition that the details of the method adopted by them should be made public.

123. For the purpose of obtaining a picture by the daguerreotype process, silvered copper plates are employed. After having been cleaned extremely well, they are rendered sensitive by exposure to the vapour of iodine, bromine, &c.: and, having been placed in a camera obscura, constructed for the purpose, to be acted on for the necessary time by the portrait, landscape, &c., they are exposed to the vapour of mercury, which causes the pictures, before invisible, to appear upon them. They are finally washed with a solution of hypo-sulphite of soda, and with pure water, before being carefully dried.

Silvered plates being very expensive, it is desirable to employ a cheaper material. Hence, paper has been, of late, very much used, and with considerable success. It is wetted with a solution of chloride of barium, &c., and, having been dried, is rendered sensitive by nitrate, &c., of silver: after exposure in the camera, it is developed: and is then washed with solution of hypo-sulphite of soda, and with pure water.

A *positive* picture, which has the lights and shades as in nature, or a *negative*, in which they are reversed, may be obtained, according to the way in which the arrangements are made.

The transparency and even surface of glass plates renders them well adapted for the photographic process. For this purpose they are covered with a film, which most usually consists of albumen, or collodion (a solution of gun cotton, to be described hereafter), rendered sensitive by iodine, &c.: and, after exposure in the camera, are developed by compounds modified according as the picture is to be positive or negative: and are washed with a solution of hypo-sul-

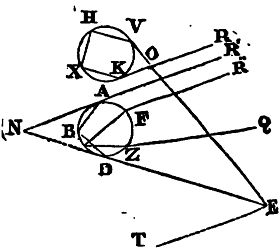
* From whom the process has been called the "Daguerreotype."

phite of soda, or of cyanide of potassium, and then with pure water. If negative pictures have been produced on the glass, positive are obtained by means of them, on sensitized paper. The photographic process is well adapted for copying engravings, &c. And a drawing may be transferred to wood, by rendering the surface sensitive, and treating it nearly as if it were paper. Daguerreotype plates may be etched: but it is unfortunate that, so delicate is the daguerreotype picture, if the etching is continued long enough to give a good impression on paper, some of the fine lines will run into each other. If, on the other hand, the etching is not continued so long, the printer, in cleaning the plate, will destroy it: and, besides, the particles of ink will be too large to express the details. But these difficulties have been, to a certain extent, overcome.

124. THE RAINBOW is formed by the decomposition of light, caused by the particles of moisture acting as minute prisms. Since, the coloured rays, which form white light, are differently refracted, they cannot enter the eye in a combined form: and the sensation of colour must, therefore, be produced. The rainbow constitutes the base of a cone, the vertex of which is in the eye, and its axis in a line passing through both the spectator's eye, and the sun which is at his back. It may be caused by the mists of waterfalls, &c., as well as by rain. The gorgeous masses of coloured light, varying in tint almost every instant, and adding so greatly to the beauty and magnificence of the falls of the Rhine at Schaffhausen, are produced in this way: being due to the decomposition of white light, by the mist rising from so vast a body of water falling through so considerable a height:—the effect can be conceived, only by those who have witnessed it.

125. The rainbow consists merely of a number of spectral images [105], arranged in a circle. The primary or inner bow, is caused by two refractions, and one reflection. The ray R′ fig. 229, is refracted at A, reflected from the inner surface at B, and having been again refracted at D, enters the eye at E. Many rays pass into the drop; but only those will be parallel and produce an effect on the retina, which are incident in the vicinity of

FIG. 229.



that point on its surface where, from the nature of the medium of which it consists, the incident ray R′A makes the *greatest* angle with the emergent ray DE. If the situation of the drop of moisture is such, that the coloured rays emerging from it nearly parallel, will enter the eye of an observer, he will perceive the corresponding colour. The greatest angle in rain water for red rays, emitted after one reflection, is 42° 30′: and for violet, 40° 30′. Rays like R″ incident on other parts of the surface of the drop, emerging in the direction ZQ, will be so divergent as not to enter the eye.

126. Let, therefore, ET, fig. 229, be a line passing from the sun through E, the eye of the spectator, and by consequence parallel to R′A: and let TED=40° 30′. If ED revolves on ET as an axis, D will describe the circumference of the base of a cone; and any rays in the direction R′A, which, during any part of its revolution, fall on the corresponding drop, will emerge in a direction E; and, since the angle between the incident and emerging rays= 40° 30′, they will be among those violet rays which, emerging nearly parallel, reach the eye, and produce on the retina the sensation of that colour. In the same way, if the angle TED=42° 30′, the emerging rays will belong to those red rays which, being nearly parallel, reach the eye, and produce the sensation of the latter colour. In this way, all the drops with which D would come into contact, were ED to revolve on ET as an axis, send to the eye at E, rays which are nearly parallel, and which taken together, form a coloured ring. The other coloured rings, will be produced in a similar manner, by incident and emerging rays, making the greatest angles, belonging to them respectively.

127. Since the sun is not a point, but a disc about 30′ in width, the coloured rings are each about 30′ wide: and the whole breadth of the rainbow is, on the average, *about 2°*.

128. Besides the primary, there is sometimes seen a secondary bow, which is outside the primary, and concentric with it: but the colours are reversed. It is produced by two refractions and two reflections: and its colours are fainter, because the more frequently light is reflected, the less intense it is. The ray R, fig. 229, enters the drop, and is refracted at K; it is then reflected from the interior surface at X, and, again, from that at H; thence emerging, it is refracted at V, and crossing the incident ray, enters the eye at E. When there are two reflections, rays incident on that point of the surface of the drop which makes the angle between the incident and emergent ray *least*, will emerge nearly parallel, and reach the eye. The least angle for red rays is 50°; and for violet 53° 30′. If, therefore, the angle made by the incident and emerging rays=50°, the nearly parallel rays, from each of the drops lying in the circumference of the base of the imaginary cone [126], will form in the eye at E the image of a red circle: and if it=53° 30′, the image in the eye will be that of a violet circle.

129. The amount of the arc, which will be visible, depends on the sun's altitude above the horizon. When the sun is in the horizon, an observer on a plain sees an exact semicircle:—on an isolated mountain top, of small breadth, he would see more than a semicircle. Rainbows forming perfect circles, are sometimes visible from the masts of ships. The higher the sun, the lower the centre of the bow, and, therefore, the less of it is above the horizon. If the sun's elevation is 42° 30′, and the observer is at the level of the sea, the top of the rainbow coincides with the horizon, and none of it is seen by him. Three, four, &c., rainbows, would be perceptible, if the light were not so much weakened, by the repeated reflections necessary to form them, that it is no longer capable of producing any effect on the retina:—the third bow would require three, and, the fourth, four reflections, &c.

There are lunar bows, likewise.

130. *Parhelia*,* called also, "mock suns," are images of the sun, occasionally perceived at some distance from that luminary. According to Mariotte, they are due to

* *Para*, beside; and *hēlios*, the sun. Gr.

particles of ice, suspended in the air, and multiplying the image of the sun—either on account of turning its rays out of their paths by refraction, or of reflecting them like mirrors. Parhelia are apparently of the same size as the sun; but they are not so bright, nor are they always round: several having various degrees of brilliancy, may appear at the same time: and their edges are often tinged with various colours. They are sometimes seen within a coloured ring, which has been noticed also round the sun and (of a smaller size) round the moon: and should not be confounded with halos. It is found by calculation, that frozen particles of water, in the shape of six-sided prisms, would form both the rings and parhelia—the latter being caused by light reflected from vertical surfaces.

131. INTERFERENCE OF LIGHT.—If a small convex lens is placed in the aperture of a window shutter one fortieth of an inch in diameter, there will be transmitted a divergent beam, in which the shadows of bodies will have coloured and parallel fringes: this will not occur, if half the light is intercepted. Hence the rays, at one side, interfere with those at the other. Two pencils of light may be made to cross each other, in such a way as either to increase, or diminish each other's intensity. These interferences strongly confirm the correctness of the vibratory theory; and they arise from a cause similar to that which [pneum. 98] produces interference of sounds. It is found that, when two equal quantities of red light are made to fall upon a sheet of white paper, there will be, in some cases, a double quantity of that light, but in others, no light whatever. The double ray is twice as bright as each single ray, when the difference of the lengths of the two beams, from the two luminous points to the red spot on the paper, is exactly the 0·0000258th of an inch, or some multiple of it. But if the difference is equal to the $\frac{0 \cdot 0000258}{2}$th, or some multiple of it, no light will be perceived on the paper. If the difference of the lengths of the rays is equal to the 0·00003225 ($0 \cdot 0000258 \times 1\frac{1}{4}$)th, the 0·00005805 ($0 \cdot 0000258 \times 2\frac{1}{4}$)th, &c., of an inch, the *red spot*, formed by the combined beams, will be of the *same* intensity as that produced by only one of them.

132. When violet rays are used, the difference must be the 0·0000157th of an inch : when the other coloured rays, quantities between the 0·0000258th and the 0·0000157th of an inch, or their multiples.

133. The interference of luminous undulations may be illustrated, by placing on a smooth table, two bits of plate glass cut from the same piece, with their divided portions in contact, and gently inclined to each other by a piece of paper placed under the edge of one of them. If a ray of homogeneous light—yellow, for instance, from a spirit lamp with a salted wick, all extraneous light being excluded —is thrown upon them, light and dark alternate bands will be perceived. The bright portions, arise from undulations which are in the same phases; and the dark ones, from those which are in opposite.

134. These facts enable us to explain why, if a minute opaque body, a slender wire or a pin for example, is held opposite to a small aperture in a window shutter, the light is coloured in a peculiar way. The bright bar in the middle, is caused by the rays of equal length passing at each side; and the coloured fringes, by the oblique rays which tend to one side or the other, and, consequently, are of unequal lengths. Black lines are formed at certain distances by total, coloured bands, by partial destruction of the white ray.

135. If homogeneous light is used, alternations of that light and dark bands, will be the result.

136. The effect produced by the interference of light, enables us to understand why coloured rings are perceived, when we look at the sun, or any other luminous body, through glass covered with particles of dust, lycopodium, &c. :—even particles of water, deposited on the glass by breathing upon it, will cause the same effect. It shows, also, the way, in which *Halos*, or coloured circles round the sun and moon [130], are formed by interference due to particles of vapour. The sun's brightness prevents solar from being seen as often as lunar halos.

137. *Colours of thick, and thin plates, grooved surfaces, &c.*—If we diminish the thickness of glass plates, &c., beyond certain limits, white is changed into coloured light, during transmission through, or reflection from them.

A soap-bubble will exemplify this fact; or two lenses of great focal length [mech. 35], screwed together so as to leave between them only a thin plate of air—the diminishing thickness of which will cause the production of different colours. The latter, enable us to estimate the lengths of waves belonging to the different kinds of light. For, their colours arise from the unequal lengths of the rays, reflected at certain intervals, from each of the surfaces in apparent contact: the difference being such as to produce, through interference, the decomposition, or the total destruction of white light. And it is evident that, as we know the curves of the lenses, these differences may easily be ascertained. The following are the lengths of the undulations, &c., according to Sir J. Herschel, deduced from admeasurements made by Newton:—

Coloured rays.	Length of waves, in parts of an inch.	No. of undulations in an inch.	No. of undulations in a second.	
Extreme red, .	0·0000266	37,640	458	millions of millions.
Red, . .	0·0000256	39,180	477	
Intermediate, .	0·0000246	40,720	495	
Orange, . .	0·0000240	41,610	506	
Intermediate, .	0·0000235	42,510	517	
Yellow, . .	0·0000227	44,000	535	
Intermediate, .	0·0000219	45,600	555	
Green, . .	0·0000211	47,460	577	
Intermediate, .	0·0000203	49,320	600	
Blue, . .	0·0000196	51,110	622	
Intermediate, .	0·0000189	52,910	644	
Indigo, . .	0·0000185	54,070	658	
Intermediate, .	0·0000181	55,240	672	
Violet, . .	0·0000174	57,490	699	
Extreme violet, .	0·0000167	59,750	727	

138. The time of vibration of a given ray, varies directly as the length of the wave of that colour, and inversely as the velocity of light. And Newton found that the thickness of the different media, at which a given colour is seen, is in the inverse ratio of their refractive indices. *Hence*, knowing a tint, and the medium which produces it,

we can find the thickness of laminæ, so thin as that it would be impossible to measure them, by any other means.

139. The colours produced in these experiments, do not depend on the air, since they are the same *in vacuo:* but on the interference of waves, which are in different phases, on account of the different lengths of the rays, reflected from surfaces that are extremely near each other. As light is reflected from both surfaces of any transparent medium, colours will always be seen, when that, through which we transmit it, is of such a thickness, as to cause the required difference in the lengths of the two reflected rays.

140. If oil, or water, is interposed between the lenses [137], the rings contract.

141. When the flame of a candle, &c., is viewed through two glass plates of equal thickness, making a small angle, besides the transmitted, we shall see also reflected images: and in the nearest and brightest of the latter, coloured fringes.

142. If a strong light is thrown on a thick concave mirror of glass, coloured rings will be perceived.

143. Mother of pearl, affords a striking example of the effects produced by grooved surfaces. If it is stamped on heated black sealing wax, the grooves, though invisibleto the eye, will be communicated to the wax, which will then present an appearance similar to that of the mother of pearl. Steel may be cut, so as to produce the most beautiful tints.

144. All these results depend on interference; and they enable us to explain, in many cases, the colours of bodies —some of which, however, are due to the partial absorption of the rays constituting white light.

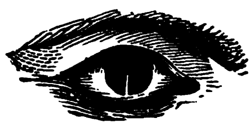
145. THE EYE, may be considered as an optical instrument, bearing a very close analogy to the camera obscura [44]. It is divided by anatomists into many parts:—we shall consider only those which are most important, so far as the present subject is concerned.

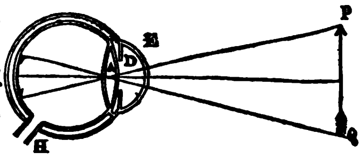
146. The eye-ball is protected by the upper and lower lids, the eye-brows, and eye-lashes. By a beautiful provision, it is exceedingly sensitive to very small, though but slightly so, to large objects:—it may be touched by the

finger, with little inconvenience: while a particle of dust causes intense pain. Its power of seeing the larger bodies, is a sufficient protection against injury from them; but those which are almost invisible, might still be productive of serious consequences. The moment, therefore, the latter come in contact with it, they are wiped away by the motion of the eye-lid, aided by the lachrymal fluid; or they are removed by the finger, &c., their presence being made known, by the pain to which they give rise. Instances are recorded, in which blindness has been caused on account of the eye having been gradually and imperceptibly destroyed by minute objects—to the presence of which, it had become insensible. As an additional security to this most important, and, at the same time, most delicate organ, it is placed in a strong socket of bone called the *orbit*. When an animal is soft and without bones, it is capable of being brought, for safety, within the body:—thus, the snail can draw in its eyes, which are placed at the extremity of its horns, whenever they are exposed to danger. The eyes of animals that are without eye-lids, such as fishes, are so circumstanced, as to receive no injury from the particles to which they are exposed.

147. The globe of the eye is surrounded by a hard membrane called the *sclerotic** coat, transparent only at E, fig. 230—the part of it which is termed the cornea,† and is more curved than the rest. A prismatic coloured membrane, called the *iris*,‡ lies behind the latter:—its plane cuts off the cornea, as it were, from the rest of the eye. A circular opening D, in the middle of the iris, is called the *pupil:* by its expansion, or contraction, it allows the proper quantity of light to enter. The *choroid*§ coat is a membrane lining the scle-

FIG. 230.





* *Skleros*, hard. *Gr.* † *Cornu*, horn. *Lat.*
‡ *Iris*, rainbow. *Lat.* § *Chōra*, a region. *Gr.*

rotic: it is covered over with a black pigment, called the *pigmentum nigrum*,* which absorbs all the light that—not contributing to the production of an image within the eye—would merely tend to render it indistinct. For a similar reason, the interiors of telescopes, and of other optical instruments, are blackened. The *retina*,† an expansion of the optic nerve H, receives the image. The *crystalline humour* A—a double convex lens—is placed within a transparent capsule, which attaches it to the outer wall of the eye. A clear, and somewhat saline fluid, called the *aqueous*‡ *humour*, lies between the crystalline lens and cornea: and the *vitreous*§ *humour*, which is within the crystalline lens, fills the great mass of the eye-ball.

148. When light falls on the front of the eye, part of it is reflected in all directions, by the white opaque sclerotic; part of it reaches the iris, and is given back in tinted rays—blue, hazel, &c., according to the colour of the eye; and part, entering the pupil, is transmitted through the crystalline lens, and refracted in such a way that the rays coming to foci on the curved surface [28] of the retina, form there an inverted image of external objects. All this may be illustrated by the eye of an ox, or other large animal, if it is opened carefully, so as to render the retina visible, through the vitreous humour: a small inverted image of any object, towards which it is directed, will then be perceived within it. Although the crystalline humour, like any other single lens [37], produces an inverted image, we refer the different portions of objects to their proper places: for, our ideas are corrected by habit.

149. Philosophers are not agreed as to whether it is the impression made by light on the retina, or on the choroid coat that causes vision:—some of them believe that both concur in the effect; and some, even, place the seat of vision in the vitreous humour. It is certain, that in a particular species of cuttle fish, an opaque membrane is found between the vitreous humour and the retina; and, in every eye, the point where the optic nerve enters it is incapable of vision:—hence, the image of any object, if thrown up on that part, is not perceived.

* Black pigment. *Lat.* † *Retē*, a net. *Lat.*
‡ *Aqua*, water. *Lat.* § *Vitrum*, glass. *Lat.*

150. The crystalline lens is more convex behind than before. Within certain limits, we can alter its convexity, so as to adapt it to objects at different distances [29]. But we possess other means of adjustment: since it is said that the eye, even deprived of its crystalline lens, can suit itself to different distances.

151. We are enabled, by habit, to judge of distance; but we are greatly aided by the presence of intermediate objects. Hence, we cannot form a correct idea of distance by water. Hence, also, the moon appears largest when in the horizon: though, in reality, its vertical diameter is then least; for, the increased refraction, consequent on the greater density of the air through which the light passes, makes its lower edge seem higher than it should be, considering the position of its upper:—and, we do not estimate the size of an object, simply by the angle under which it is seen, but we take into account, also, its distance. Hence, the moon, seen under even a less angle, seems larger, because, as there are intervening objects, we consider its distance greater than ordinary—our means of measuring that distance being more abundant. From intervening objects being invisible, the distance of a fire, at night, is not correctly estimated by an observer.

152. We often attribute a diminution of light, which arises from other causes, to increased distance:—hence, objects seem farther off in a fog. A person who has been blind from infancy, but who suddenly obtains his sight, has no idea of distance: and thinks the surrounding objects actually within his eye—as the picture, by which he becomes conscious of their presence, really is.

153. We judge of size, also, by comparison. A circular aperture, in the centre of a large disc, seems very different, in diameter, from one of exactly the same magnitude, in a much smaller disc. And an object, in a large church, such as St. Peter's at Rome, may appear small; while, in a lesser building, it would seem immense. The very dimensions of the building itself are, as it were, diminished, when every part, and every decoration, is in proper proportion—since, then, no part invites attention more strongly than the rest: and our notice is not attracted to the vast extent of the edifice, by the prominence of any

thing which, whatever may be its actual size, seems either too large or too small for the place in which it is situated. From this cause, it is necessary to visit St. Peter's many times, before it can be fully appreciated.*

154. As the difference of density between water and the eye, is not so great as between air and the latter, light is not turned so much out of its course, by refraction [11], in passing from water to the eye, as in passing to it from air. Hence, the eyes of fishes are extremely convex.

155. Spherical aberration [102] is corrected, in the crystalline lens, by its peculiar curvature; and by the concentric layers, of which it consists, increasing in density, as they approach the centre. The refractive power, therefore, of its different parts, is not the same.

156. Single vision with *two* eyes arises partly, perhaps, from habit and partly from the fact that the axes of both eyes are directed to the same *precise* spot—in which we feel that two different objects cannot be at the same time: and, therefore, though unconsciously, we conclude that there is but one. A very slight alteration in the shape of the eye, caused by the finger, &c., will produce a double image. And persons when intoxicated, see double, from being unable properly to manage their eyes. We may render the representation of a candle in the eye double, by looking at it while the eye is in some measure directed also to objects beyond it. *Squinting* arises from the shutting of one eye, to prevent two images being formed by one object, through organic imperfection of vision.

157. *The Stereoscope.*†—No picture can give an exact representation of a solid: for the eyes, to a certain extent, look *round* it, each of them seeing more of one side than of the other, and the two pictures in the eyes not being absolutely the same. This may be easily proved, by placing a small cylinder of any kind, covered with paper, on the table, and marking by dots, &c., the width of the part seen by each eye when the other is closed. It will soon be found that marks on the left hand side, visible to the left eye, will not be visible to the right eye; and *vice versa*. The stereoscope has been invented to meet this

* See "Elements of Architecture," p. 167.

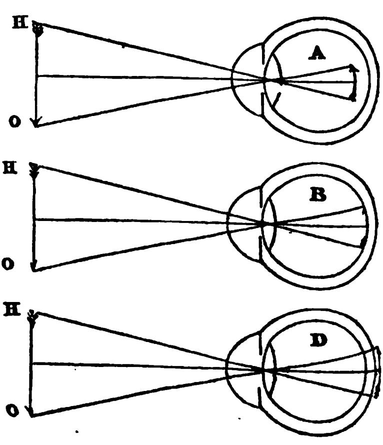
† *Stereos*, solid; and *skopeo*, to examine. Gr.

peculiarity of vision. It consists usually of a small box, in the back of which is placed an oblong slide, containing two photographic pictures of the same object, taken in two slightly different positions of the camera [opt. 123]. These pictures are both seen at once, with transmitted, or reflected light—according as they are transparent, or opaque—by means of two small tubes, each containing a lens, and adjusted to the circumstances of, and distance between the eyes of the observer: so that each eye sees a picture corresponding to it. When we look into this instrument, the different objects in a room, &c., seem to stand out as distinctly, in form and position, as in nature; and it is difficult to persuade ourselves that we are looking at a flat surface.

158. Some insects and crustacea have more than two eyes; and many of them have a great number. The house-fly has 4,000 lenses; 17,000 have been counted in a butterfly; 24,000 in the two masses of eyes of the dragon-fly; and 25,000 in the Mordella beetle. Sometimes the cornea is divided into a great number of compartments or *facettes*:—that of a single eye has been found to contain so many as 20,000.

159. LONG, AND SHORT SIGHT.—The focus of the crystalline lens is, with some persons, nearer than, and with others, beyond the retina:—the former are said to be "long," and the latter "short-sighted." The vision of short-sighted persons is improved by age, and that of long-sighted, made worse:—since the convexity of the crystalline humour is, in both cases diminished by time. The eyes of short-sighted per-

FIG. 231.



sons magnify objects—because they view them at a smaller distance [40]. Concave glasses correct short sight, by increasing the divergence of the rays, before they enter the crystalline lens, and thus [29] removing their focus to a greater distance. Convex glasses, for an opposite reason, correct long sight. Fig. 231, shows what would be the position of images from any object HO, when the focal length of the crystalline lens is less than, equal to, or more than it should be:—A represents short, B correct, and D long sight.

160. We can render ourselves, to a great extent, unconscious of external objects, without shutting our eyes, merely by throwing them out of focus: which, while it prevents our meditations, &c., from being disturbed by the formation of images within the eye, leaves the latter always ready for instant use; and by a certain amount of communication with the external world, prevents, in many cases, great inconvenience.

161. The faculty of memory, and the functions of the retina, seem, in some way, intimately connected. We cannot, for example, bring clearly to our recollection, a building we have formerly seen, without first banishing from the retina, the image of one that is before us.

162. Sometimes, the crystalline lens is rendered opaque by *cataract*. In this case, when the disease has progressed to a certain extent, the crystalline humour is depressed by an instrument; after which it is gradually absorbed, on account of a provision made by nature for the purpose—unless it is, at once, removed. Its place must be supplied by a lens.

163. Some eyes are insensible to certain colours: and when they receive white, or other light, containing them, the ray is decomposed, and only the part which is combined with the colours to which they are insensible, becomes visible to them. Thus, when an eye is insensible to green, white light will appear red: since green and red constitute white—or, in other words, are *complementary* colours. When it is insensible to blue, green will seem to be yellow—since the latter is constituted of yellow and blue. The eye may be rendered insensible to any colour, by looking steadily at it. If we place a red wafer on a sheet of white

paper, and look at it for some time, the paper will appear covered with green spots of the same size as the wafer. That is, the surface of the retina will have become insensible to the red part of the white light, to an extent equal to the image of the red wafer. When colours are placed in juxtaposition, they modify each other, the complementary colour of each being added to the other. Hence, colours, when near each other, may be not at all the same as when separate; and the change they suffer may produce an agreeable effect, or the contrary. To foresee and appreciate these changes, is one of the elements of good taste in colours. And such modifications of colour, should be borne in mind by designers of carpets, room paper, &c. Black patterns, printed on a red ground, would appear green. When crimson, red, and orange, are placed in contact, the former will acquire a purple, and the latter a yellow tone.

Curious mistakes are sometimes made by persons insensible to certain colours. Thus, red silk stockings have been chosen for, and worn as black, by a distinguished philosopher whose eye was insensible to red. The same object, it is probable, never appears of precisely the same size or colour, to any two persons. Some animals may perceive rays of light, not cognizable by our senses; just as some may, it is likely [pneum. 70], perceive sounds inappreciable by us.

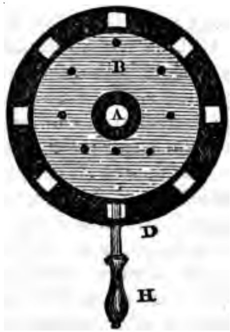
164. Two transparent bodies will become opaque when superimposed, if each absorbs the colour complementary to that which is transmitted by the other. Thus, a plate of red, laid over a plate of green glass, will transmit no light; since one plate will intercept all the green, and the other all the red—that is, all the white light, green and red being complementary.

165. *The Phenakistiscope.**—Impressions which succeed each other with a certain degree of rapidity [pneum. 75], are judged by the mind to be continuous. The "Phenakistiscope" is an optical instrument constructed on this principle. It consists of a disc of card D, fig. 232, containing 8, 9, &c., small apertures, and capable of being made to revolve rapidly about a horizontal axis A, attached to the

† *Phenakē*, a deception—from *Phenakizo*: and *scopeo*, I view. *Gr.*

handle H. Within the circle containing the apertures, is fixed a small disc, having some object, in gradually varying positions, painted upon it. The disc in the figure, for the sake of simplicity, is supposed to represent a ball moving up and down, the dot which represents its lowest position being nearest to, and that which represents its highest farthest from the centre; the intermediate positions, being indicated by dots gradually changing their distances from A. If—the painted side of the disc being held towards a mirror, and the whole being made to revolve —the person who grasps the handle, look steadily at the mirror, through the openings, as they pass in succession before his eye, impressions of the object, in different and successive positions, will be produced; and, since one is not effaced until another is formed, the sensation will be continuous, and the ball will seem to move up and down. Any thing may, in this manner, be made continually to change its position: and thus a variety of pleasing effects may be obtained, in a way very simple, but very surprising to those who do not understand the cause.

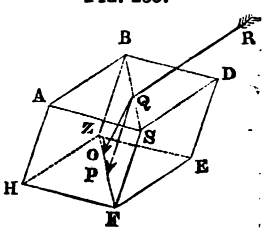
Fig. 232.



166. The eye does not perceive objects, if their image passes too quickly across the retina. Hence the rapid motion of a cannon ball prevents it from being seen: while a bomb-shell, which moves more slowly, is distinctly visible.

167. Double Refraction.—Transparent bodies, generally transmit but a single image of a given object. This is not, however, invariably the case. For, some substances—such as Iceland spar—transmit two: the white ray being decomposed not into different coloured rays, but into white ones, having, as we shall

Fig. 233.



find hereafter, very different properties. This is called "double refraction." The double image of a single object was first observed by Erasmus Bartholinus in 1669.

168. If a ray R, fig. 233, is incident perpendicularly on a rhomboid of Iceland spar ABDEFH, at Q, it will be divided into two rays QP, and QO—the former in the direction of the original ray, and therefore unrefracted, and the latter refracted towards Z. If QR is not incident on the face ABDS, at a right angle, one of the rays will be refracted in the ordinary manner—and is therefore termed the *ordinary* ray, but the other will be turned towards an imaginary line connecting the acute angles F and B—and is called the *extraordinary* ray.

169. A plane BSFZ, passing through the two rays, is called the *principal section* of the crystal. The one, or more lines, or planes, in a double refracting crystal, in which there is no double refraction, are said to be *lines, axes,* or *planes of double refraction*. There is but a *single* axis, in Iceland spar; and it is a line, connecting its two obtuse trihedral angles A, and E, fig. 233. The axis is *real* when it actually exists, as in Iceland spar. It is *resultant* when, as in mica, it arises from two doubly refracting forces neutralizing each other. The axis is a particular direction, and not a perpendicular line; for if we separate a piece of Iceland spar into smaller crystals, each will have its axis; and the axes of all will be parallel to the original one. If the extraordinary ray—or that which is entirely out of the plane of incidence, is refracted towards the axis, or plane of axes, it is called a *positive* axis; if otherwise, a *negative*. Quartz is an example of a positive; Iceland spar, of a negative crystal. Generally speaking, both rays are turned, not only out of the same line, but also out of the same plane. In substances, such as quartz, Iceland spar, &c., which have only one axis, only one ray undergoes extraordinary refraction. In those having two axes, both rays are extraordinarily refracted. Doubly refracted rays, after leaving the crystal, are parallel.

170. Double refraction may be illustrated, by putting a small dot, with ink, on a piece of white paper, and laying a crystal of Iceland spar upon it: the dot will appear *double*; and, on moving the crystal round, one dot will

seem to revolve round the other. If we draw a black line on the paper, the two images of the line will be farthest asunder, when the line is in the same plane as the greatest diagonal of the crystal, or in a plane parallel to it. When the crystal is turned round, the images gradually approach: and they coincide, when the line is in the same plane as the shortest diagonal or in a plane parallel to it; for the ordinary and extraordinary rays are then in the principal section.

Or, we may cover all but one side of the rhomb with tinfoil, and make a small hole in the foil, over the face of the crystal opposite to that which is not covered. On looking at the aperture, through the crystal, a double image of it will be seen.

171. If two crystals are placed together, so that their principal sections are parallel, the ordinary ray will be subdivided in passing through the second crystal; if they are arranged so that they are perpendicular, the ordinary ray will suffer extraordinary, and the extraordinary ray ordinary refraction. In intermediate positions—unless they make an angle of 45°—the ordinary and extraordinary rays will be subdivided into rays of unequal intensity. In making experiments with the second crystal, we shall find on examination, that the two rays produced by the first, have the same properties, but at different sides.

We can test light, which we suspect to possess the characteristics belonging to either of the rays arising from double refraction, by means of the second crystal.

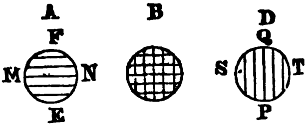
172. POLARIZATION* OF LIGHT.—Under ordinary circumstances, refracted and reflected light retain their properties. But this is not invariably the case: for, it may be so modified as to be incapable of transmission, or reflection, at certain angles—and it is then said to be *polarized*. That rays of light have, in certain circumstances, different properties at their different sides, was remarked by Newton, in examining the rays produced by double refraction. But Malus discovered in 1808, that light may be polarized by reflection: since that which was reflected from the windows of the Luxembourg, unlike ordinary

* *Polus*, a pole, *Lat.*:—because the rays of light have different properties, at their different *sides*.

light, gave with a rhomboid of Iceland spar, rays of very different intensity. The angle at which light must be incident [11] on any given substance, in order that it may be polarized, is termed the *polarizing angle*, or the *angle of polarization* of that substance: a plane passing through the axis of the polarized ray, and cutting those sides of it which refuse to be reflected at the angle of polarization, is called the *plane of polarization.*

173. We may, perhaps, have some conception of the nature of polarization, if we suppose B, fig. 234, to represent an ordinary or unpolarized ray: A, and D, being its two elements. The sides of A, represented by E and F, have the same properties as the sides of D, represented by S and T. Hence, if A is incapable of reflection at a certain angle, when either of the sides E and F is presented to the reflecting body, D, also, will be incapable of reflection at the same angle, when either of the sides S and T, is presented to the same body. A plane passing through the axis of A, and at the same time through E and F, or through the axis of D, and at the same through S and T, will be the plane of polarization of the respective rays: these planes of polarization of the two elements are, therefore, at right angles. At a position between, for instance E and N, or P and T, the properties of the rays are intermediate—the nature of their modification depending on whether the given point is nearer to E or N, to P or T. And if the ray is incident on the reflecting surface, at these intermediate points, it will be *partially* reflected.

FIG. 234.



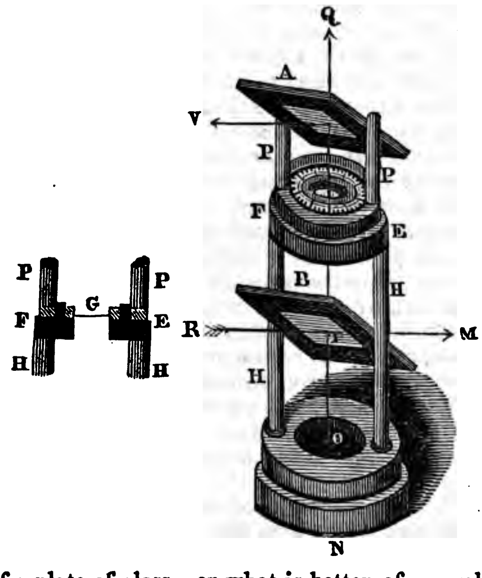
A self-luminous body never emits polarized light. But it may be capable of reflecting light. Hence though comets emit polarized light, it is not certain that they have no light of their own [8].

174. When light is polarized, it is separated into two portions, which are produced by vibrations in planes at right angles. Polarization, therefore, seems to reduce vibrations which, in ordinary light, occur in planes passing *through* the axis of the ray, and making all possible angles

with each other, to vibrations in two planes at right angles.

175. *Polarization, at the first surface of transparent bodies.* The "polariscope," an instrument for polarizing light, or ascertaining if it is polarized, may be constructed like that represented, fig. 235. A stand N, having in the centre an ordinary mirror O, supports pillars H, H, to which is attached, by pins, the mirror B. The latter con-

FIG. 235.



sists of a plate of glass—or what is better, of several plates—fixed in a frame, and capable of being adjusted, so as to make any angle with the horizon. The upper extremities of H, H, are inserted in an annular frame (shown in section at FE) graduated at its upper surface. A similar frame, containing a plate of glass, intended as a stand or *stage* for objects, and to be used as we shall describe hereafter, is placed within FE. This interior frame can be moved round through any number of degrees—indicated

by a graduated circle on the upper surface of FE. Outside this circle is placed another frame, which supports the pillars P, P, and is movable also, through any number of degrees—indicated likewise, by the graduated arc on the upper surface of FE. A mirror A, fixed to P, P, by means of pins, may be adjusted so as to make any angle with the horizon. It is evident that the planes of reflection [65] of the mirrors A and B, may be arranged so as to make any angle with each other.

176. If, while B makes an angle of 33° 48′ with a vertical line QO, we cause a ray R to be incident upon it [11] at an angle of 56° 12′, the angle of polarization for glass, part of it will pass away to M, and another part will be reflected down perpendicularly on the mirror O, and thence through the *polarizing mirror* B and the glass plate in FE, to the *analyzing mirror* A—supposed, for the present, parallel to B: from A, it will move towards V. If, however, without altering the angles which A and B make with the horizon, A is moved round 90°, the ray thrown upon it from O, will be no longer reflected. This ray, therefore, has different properties at its different sides; that is, it has been polarized, by reflection from B. If A is turned round another 90°, its plane of reflection will again coincide with that of B—since it has been moved round 180°: and it will once more reflect the ray, thrown up by the mirror O. At intermediate positions of A, the ray from O will be reflected by A to an extent dependent on whether, or not, the angle through which A has been moved, is near either 90° or 180°.

177. If, while the planes of reflection of A and B make with each other an angle of 90°, we cause the mirror A to make an angle of 36° 46′ with the vertical line QO, a portion of the latter will be reflected from A: but it will cease to be reflected from that mirror, which is now at the angle of polarization for water, if we breathe upon it.

178. Different substances have different angles of polarization: which may be found, either by experiment, or calculation. When light is polarized by reflection at the first surface, "the index of refraction is tangent to the angle of polarization:" and "the tangent of the angle of polarization is equal to the sine of the angle of incidence,

divided by the sine of the angle of refraction corresponding to the given medium." This enables us to ascertain the angle of refraction, belonging to minute portions of transparent minerals: and also that of bodies which are translucent, but not transparent [6].

179. Trigonometry enables us to deduce, from this law, that—

"The complement of the polarizing angle, is equal to the angle of refraction."

"At the polarizing angle, the sum of the angles of incidence and refraction, is a right angle."

"When a ray of light is polarized by reflection, the reflected ray forms a right angle with the refracted ray."

180. The angles of polarization, found by experiment, agree very nearly with those obtained by calculation, as appears from the following—

Substances.	Angle of polarization, found by experiment.		Angle of polarization, found by calculation.	
Air,	45°	00′	45°	00′
Water,	53	14	53	11
Fluor spar,	54	50	55	9
Sulphate of lime,	56	28	56	45
Crown glass,	56	12	56	45
Rock crystal,	57	22	56	58
Mother of pearl,	58	47	58	50
Iceland spar,	58	51	58	51
Sulphur,	64	10	63	45
Diamond,	67	38	68	1

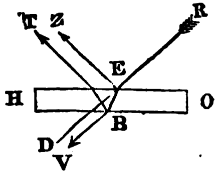
181. If the light reflected from B, fig. 235, is very intense, a coloured portion is reflected from A, even when the planes of reflection of A and B, are at right angles. This arises from some of the ray not being polarized, on account of its different coloured elements having different angles of polarization. For, with water, the polarizing angle of the red rays is 53° 4′, but that of the violet 53° 19′, the difference of the angles being 0° 15′. And, with plate glass, the polarizing angle of the red rays is 56° 36′, but that of the violet 57° 55′, the difference being 1° 19′.

182. Light may be polarized, by reflection from black ebony and other non-metallic opaque bodies. Metals, and some transparent substances, do not polarize it fully: hence, the glass mirrors which are employed to polarize

by reflection, are not covered by an amalgam of mercury. The glass surface itself acts as a reflector ; and it is sometimes blackened, to prevent rays from the surrounding objects interfering with its results.

183. *Polarization, by reflection from the second surfaces of transparent bodies.*—If a ray of light R, fig. 236, is incident on a plate of glass HO, part of it will be polarized, and reflected to Z ; another part will be refracted to B, then reflected, and ultimately refracted to T : thus adding to the brightness of the polarized light, reflected from the first surface.

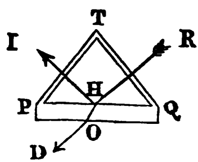
Fig. 236.



184. When light is polarized at a second surface, "the index of refraction is co-tangent to the angle of polarization." And, as with polarization by the first surface [179], the angle made by the refracted and reflected rays $=90°$.

185. *Polarization, at the separating surfaces of two media.*—When a ray is incident on the separating surface of two media, of different refractive powers, "the angle of polarization is equal to the index of refraction." Thus, if the hollow triangular prism of glass PTQ, fig. 237, is filled with water, the ray HI will be polarized, provided RH makes with the glass plate PQ, an angle$=48° \, 47'$. For, the index of glass, the more refracting of the two substances, is 1·525; and that of water, the less refracting, 1·336. The index of the separating surface will, therefore, be $\frac{1 \cdot 525}{1 \cdot 336}=1 \cdot 1415$: which is the tangent of an angle of $48° \, 17'$. In this case also, the angle made by the reflected and refracted rays$=90°$.

Fig. 237.



186. The water must have a prismatic form, like what is represented in the figure :—for if its upper surface were parallel with that of PQ, no angle of incidence on its first surface, could be given to the ray RH, which would make the angle of incidence on the separating surface, such as would cause polarization.

187. *Polarization, by successive reflections.*—A certain angle of incidence is, as we have mentioned [176], required for complete polarization :—but partial polarization will be produced by reflection, at any angle. This may be proved by altering B, fig. 235, so that it will make with the vertical line QO some angle differing from 33° 48′. The more perfectly the ray is polarized, at a given angle, the less of it will be reflected from the mirror A, when the latter makes the polarizing angle with the ray from O—the planes of reflection of the two mirrors being at right angles.

188. The law of tangents [178] announced by Dr. Brewster, leads to the conclusion, that refraction takes place before a ray actually comes in contact with the refracting substance; and that the angle of polarization for every substance is, in reality, 45°. For, if we suppose half the refraction to take place before, and half of it after the ray has become incident, it will be found that in every case the angle of incidence made by the ray is 45°.

189. *Polarization, by ordinary refraction.*—On examining the transmitted ray M, fig. 235, we shall find it to contain that portion of polarized light which has been separated from the polarized ray, produced by reflection. And if it had passed, at the polarizing angle, through a bundle of plates, instead of through but one, it would have been completely polarized—as also the elements of opposite polarization, from which it would have been separated by reflections from the various surfaces. Hence the ray, polarized by reflection, will, when more than one plate is used [175], be brighter than if there were but one. The ray polarized by refraction, differs from that which is polarized by reflection, in being capable of reflection, when that which is polarized by reflection cannot be reflected; and *vice versa*. That is, the planes of polarization belonging to the reflected and transmitted rays are at right angles.

190. According to Dr. Brewster, "the number of plates required to polarize light, at any angle, multiplied by the tangent of the angle, is a constant quantity." That is, "the number of plates is inversely proportioned to the tangent of the angle which the ray makes with the

plates;" and, as will be perc ved by the following table, the observed and the calculated numbers are nearly the same—

Number of Plates in each bundle.	Calculated angle.	Observed. angle.
8	78° 52′	79° 11′
10	76 24	76 33
12	74 2	74 00
14	72 15	71 30
16	69 40	69 4
18	66 43	66 43
21	63 39	63 21
24	61 00	60 8
27	56 58	57 10
29	54 50	55 16
31	53 16	53 28
33	51 00	51 44
35	50 23	50 5
39	46 50	47 1
41	45 49	45 35
44	44 00	43 34
47	42 00	41 41

Some have supposed, that plates which are not at the polarizing angle, are incapable of polarizing light, whatever may be their number.

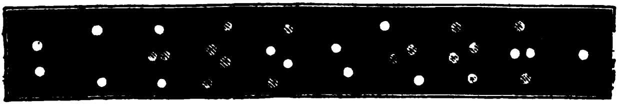
191. If the angle is not such as corresponds with the number of plates, the polarization of the transmitted ray will be more or less perfect, according as the angle is nearer to, or farther from the proper one. The unpolarized part, is not, however, mere ordinary light:—it has suffered a physical change [187] which causes it to be afterwards more easily polarized.

192. When we examine polarized light, with a bundle of plates making the polarizing angle with the ray, if we cause the plates to revolve, as it were, on the axis of the ray, the latter will, in certain positions of the bundle, be totally, in others, partially, and, in others, not at all, transmitted by the plates.

193. *Polarization, by double refraction.*—If we examine each of the two rays, into which ordinary light is resolved by the double refracting crystal [168], we shall find that each is completely polarized; and that their planes of polarization are at right angles. Supposing A,

fig. 238, to represent the double image of the aperture in the tinfoil [170], if the rays are transmitted through

FIG. 238.



another rhomb, in contact with, or very near, the first [171]—both rhombs having all their sides respectively parallel, as if they formed but a single rhomb—the aperture, in the tinfoil will, on looking at it through the two rhombs at once, assume the appearance indicated by B. And, if, without destroying the parallelism of the contiguous surfaces of the rhombs, we turn round the second one or that next the eye, we shall see four rays of unequal brightness, as represented at D, instead of two; turning it round still more, they will seem four also, but equally bright, as at E; turning it still further, four unequally bright, as at F; and when we have turned it round 90°, only two will be seen, as at H: turning it round still more, four will be seen, as at O; and the appearances represented by P, and N, will succeed; until, when we have turned it round 180°, we shall see but a single ray, as at T.

194. When light is polarized, by reflection from glass at its angle of polarization, it agrees in its properties with the ordinary ray of a double refracting crystal, the principal section of which corresponds with the plane of reflection. Consequently, the plane of reflection in mirrors, and the principal section of crystals, have an analogous effect—dependent on the *side* of the ray, presented.

195. Partially polarized light affords two images, with doubly refracting crystals; but, unlike those produced by ordinary light, they are not of equal intensity.

196. *Polarization by absorption.*—Some natural bodies, such as the tourmaline and agate, polarize light, in the same way as a sufficient number of plates [189] at any angle. If a thin transparent plate of agate, is cut in a direction perpendicular to its siliceous layers, it will,

when we attempt to send ordinary light through it, transmit but one of its polarized elements. On turning the agate round 90°, we shall find that the element transmitted, is not the same as at first.

197. If, from a transparent crystal of brown tourmaline, which is generally crystallized in the form of a long prism, we cut longitudinally, that is, in a direction parallel to the axis of the prism—the direction of the principal axis of the crystal—a plate about the 30th of an inch in thickness, and polish it, we shall find, on looking through it at the two rays produced by the rhomb partially covered with tinfoil [170], that, as we turn it round, sometimes one, and sometimes the other of them will disappear; and sometimes both, partially.

198. We may decompose ordinary, or examine polarized light, with agate, or tourmaline:—but the former does not polarize completely, if the plate is not sufficiently thick, or if the light is too intense.

199. When the sky is obscured by but few clouds, a portion of light, in its passage to the earth, becomes polarized. The maximum of polarization occurs in a circle about 90° from the sun. According to Arago, rays from the moon contain a large portion of polarized light.

200. We can obtain the elements of ordinary light, whether they differ in colour or in polarity, by very analogous means. The different refrangibility of the coloured rays enables us to separate them, by means of the prism [105]; the different refrangibility of the polarized rays enables us to separate them, by the doubly refracting crystal [168]. We can separate the coloured elements, by reflection [181]; we can separate the polarized elements, in the same way [172]. We can separate the coloured rays, by absorption [144]; we can separate one of the polarized elements of light from the other in the same manner [197].

201. INTERFERENCE OF POLARIZED LIGHT.—Colours are produced by interference [131], when a polarized ray undergoes double refraction—provided the doubly refracting plate is not so thick as to produce too great a separation of the images. One of the rays emanating from the doubly refracting crystal, is retarded to the amount of half

a vibration: but the cause of this retardation is not well understood.

202. The colours arising from the interference of polarized light, may be illustrated, by placing on the glass stage of the polariscope, fig. 235, a thin slice of selenite, and transmitting through it polarized light. When it turned round to a certain position, the mirrors A and B, having their planes of reflection parallel or at right angles, a brilliant coloured image will be seen in A: and the nature of the colour will depend on the thickness of the selenite. Whatever colour is seen when the polarizing planes of A and B are parallel, its complementary colour will be perceived if they are at right angles, A having been turned round 90° without altering the angle it makes with QO. If, without altering the mirrors, we turn the selenite round, by means of the movable glass stage, the colour will not change, but will gradually disappear, and will at length vanish, when the plane of primitive polarization passes through one of the lines termed *neutral* axes:—for the ray being then no longer divided into two, there can be no interference, nor, by consequence, any colour. On continuing the rotation of the selenite, the colour gradually reappears: —but it disappears again, when the plane of polarization passes through the second axis of the crystal. The colour is most brilliant, when the plane of polarization lies in one of the lines which make an angle of 45° with the neutral —which may be called the *depolarizing axes*.

203. The light of the sky from a window, or that of a lamp, or candle, may be used in these experiments. And the mirrors will be known to make the proper angles with the rays, when its plane of reflection, being 90° from that of B, a dark spot is seen in the centre of the analyzing plate.

204. If the plate of selenite is not of uniform thickness, varying colours, dependent on the varying thickness, will be produced. Mica, &c., may be used instead of the selenite.

205. If a rhomb of Iceland spar is placed in the polariscope, on one of the faces produced by cutting off the aspices of its obtuse angles, and polishing the resulting triangular surfaces, the beam of polarized light will pass along the axis, and form a series of coloured rings, intersected by a

black cross, when the planes of reflection of the polarizing and analyzing plates are at right angles: but, if these planes are parallel, colours complementary to the former, and a white cross, will be produced.

206. The same results will be obtained, on transmitting light along the axis of any other *unaxial** crystal—whether it is positive or negative. But, though the rings are the same, their properties are very different: for, if we superimpose two equally thick plates of a positive and negative crystal—of calcareous spar, and zircon, for instance—there will be no rings: though each, separately, would produce them.

207. When a crystal has two axes of double refraction, if light is transmitted along them, there is perceived a double system of rings, combined to a certain extent, and traversed by a black cross: and if the stage of the polariscope, on which it is placed, is moved round 45°, the cross opens into two hyperbolic curves. The dark lines, forming the cross, show where the polarized ray passes through unchanged, and are called *lines* or *axes of no polarization*, and, by some, *optical axes*—but improperly, as all axes in crystals are optical. If the two axes of no polarization are but slightly inclined to each other, as in nitre, carbonate of lead, &c., two systems of rings which surround the axes, and are themselves surrounded by the same ring, may be seen at once: but if they are greatly inclined to each other, as in topaz, mica, &c., only a system of rings surrounding each axis is perceptible.

208. The production of coloured rings by polarized light, enables us to detect a doubly refracting structure, where we should not, otherwise, have been able to discover it. Thus unannealed glass appears, in ordinary circumstances, like any other; but, placed on the stage of the polariscope, it produces a beautiful coloured image—which, unlike that obtained from quartz, is of a form depending on the figure and size of the piece experimented upon, and which perpetually assumes new and beautiful shapes, as the stage is turned round.

209. Animal jelly, when pressed with sufficient force, assumes a doubly refracting texture; and produces the

* Having but one axis [169].

tints and cross, when the planes of reflection of the polarizing and analyzing plates are at right angles. Glass, under pressure, the crystalline lenses of animals—particularly of fishes, &c.—exhibit, also, the tints of polarized light.

210. If, instead of the analyzing plate of the polariscope, fig. 235, we use a combination consisting of several plates of glass, or mica, and look down through it from above, at the crystal on the stage, we shall see colours complementary to those observed when we look from V.

If the crystal is very small, it must be placed very near both the eye and the analyzing plate:—or a convex lens of about two inches focus may be held above it, for the purpose of throwing a magnified image on the analyzing plate.

211. Circular, &c., Polarization.—If a thin plate of regularly crystallized quartz, is cut in a direction perpendicular to its axis, and placed on the stage of the polariscope, on looking into the analyzing plate, in the usual way, a few rings will be perceived at the circumference of the crystal. But the centre will be of a uniform tint, provided the plate is of a uniform thickness: and the nature of the colour will depend on the thickness. If the tint is red, when the analyzing plate is made to revolve, it will change, successively, to orange, yellow, &c., to violet: which seems to indicate, that the different colours are polarized in planes lying in the direction of the radii of a circle. Corresponding effects are produced, when other tints are used.

212. Some specimens of quartz, change from the red to the violet, when the plate is made to revolve from the left to the right, others, when it is made to revolve from the right to the left:—the former are termed *left handed*, and the latter *right handed*. The amethyst is composed of alternate layers of each. The thicker the plate of quartz, the larger the arc through which the analyzing plate must be moved round, to cause a change from one tint to another. This fact is seen more clearly by using homogeneous light, which, indeed, is most conveniently employed in many of these experiments. If we use that from red glass, when the quartz is 0·04 inches thick, the red spot in the centre

of the crystal will be brightest, when the planes of reflection and polarization are at right angles; and the tint will cease to be visible, when the analyzing plate is moved through an arc of 17° 49′. With a crystal double that thickness, the analyzing plate must revolve through an arc of 35°. Two right, or two left handed crystals produce an effect which is the same as that of a crystal, the thickness of which is equal to the sum of their thicknesses. But, if one is right, and the other left handed, the effect will be that of a crystal which is equal to the difference of their thicknesses:—and it will be right or left handed, according as the right, or left handed used is the thicker.

213. Circular polarization is not confined to quartz; it is found also in fluids. If a brass tube closed with glass at its lower end, and about six or eight inches in length, is filled with oil of turpentine, and placed on the stage of the polariscope, beautiful coloured images will be produced; and the planes of polarization will be found to rotate from right to left. The tube should be tolerably long, as the action of the turpentine is not so intense as that of the quartz. Substances between which little or no difference exists, in other respects, are distinguished by their being right, or left handed.

214. Rectilinearly may be changed into circularly polarized light, by causing it to suffer, in the interior of a glass parallelopiped, two reflections which are at angles of 54° 30′, and are in a plane inclined 45° to the plane of polarization of the ray:—the emergent beam will possess the properties of that which is produced by double refraction through the rock crystal [212].

215. Circular may be changed into rectilinear polarization. Fresnel found that, if the glass parallelopiped is sufficiently long, the light will emerge, circularly polarized, after 2, 6, 10, 14, &c., reflections; but rectilinearly polarized, after 4, 8, 12, 16, &c., reflections.

216. *Elliptical Polarization.*—Circular polarization is produced by two systems of undulations of equal amplitude, polarized in planes at right angles, and differing in their paths, by the quarter of an undulation. But if the difference amounts to some other fraction, the polarization will be "elliptic."

Elliptically polarized light, is obtained by a series of reflections from metallic surfaces;—eight reflections from steel, and thirty-six from polished silver, will polarize completely.

217. Elliptically may be obtained from rectilinearly polarized light reflected from a surface of mica, which has acquired a silvery lustre by exposure to a red heat—the plane of reflection being inclined to that of primitive polarization.

218. Elliptical, like circular polarization [215], may be changed into rectilinear, by certain intermediate numbers of reflections. Light is elliptically polarized after 3, 9, 15, 21, &c., reflections from steel, at an angle of 86°; but rectilinearly, after 6, 12, 18, 24, &c.

219. Some crystals possess what is termed *dicroism;** —that is, they afford different colours, according to the direction in which the light is transmitted through them. When such crystals are placed on the stage of the polariscope, the tints vary with the inclination of the principal section to the plane of polarization.

220. Fresnel established, by experiments, in conjunction with Arago, that "two beams of light, polarized on the same plane, can produce fringes [131] by interference." That "two beams polarized at right angles, cannot produce them—even when brought to the same plane of polarization. But, that if they are polarized, at intermediate angles, fringes of intermediate brightness may be obtained with them."

* *Dis*, twice; and *chrōma*, colour. *Gr.*

INDEX.

DUBLIN:
ALEX. THOM & SONS, 87 & 88, ABBEY-STREET,
PRINTERS TO THE COMMISSIONERS OF NATIONAL EDUCATION.

IRISH NATIONAL SCHOOL BOOKS.

FIFTH BOOK OF LESSONS, 12mo, 416 pages, Price Nine Pence.

These progressive lessons are particularly suited to more advanced pupils, and include subjects omitted in the former volumes of the series, or only cursorily mentioned. The treatise on History and Chronology, commenced in the Supplement to the Fourth Book, is completed in the Fifth. With the exception of the historical portion, and a few choice poetical pieces, the lessons are altogether scientific, and contain a mass of information on the various branches of general Science and of Natural Philosophy. The Fifth Book, with the two preceding numbers of the series, is designed to be carefully studied—not merely read like the ordinary lesson books.

READING BOOK FOR FEMALE SCHOOLS, 12mo, 416 pages, Price Nine Pence.

Of the series of Irish National School Books, the Reading Book for Girls is one of the most attractive and useful. It is not intended to supersede, in female schools, the use of the Third and Fourth Books of Lessons, but as an accompaniment and addition to those books. The subjects are diversified, and together form a complete manual of the moral and domestic duties of females, and cannot be read without producing the most beneficial results. The selections from the poets are of great variety. The sketches of History and Chronology, comprising sixty-five pages, are in substance the same as those in the Fourth Book and Supplement, and constructed on a similar plan.

AN INTRODUCTION TO THE ART OF READING, 12mo, 252 pages, Price Seven Pence.

The object of this book is to assist teachers in giving instruction in the Art of Reading, by regulating the pauses and accentuation. It contains an Introduction to Elocution, a Synopsis on Accentuation, and a Synopsis of Intonation. The pieces are mostly taken from the Third Book. If used by a careful and patient teacher, this work may be made exceedingly useful.

BIOGRAPHICAL SKETCHES OF BRITISH POETS, 12mo, 516 pages, Price One Shilling.

The Biographical and Critical Sketches in this work have been compiled for teachers, and such of their pupils as may be qualified to profit by the study of literary biography. The lives commence with Chaucer, and end with Burns. They are rendered additionally interesting by a series of criticisms selected from the most distinguished writers. The work is calculated "to expand and strengthen the mind, to foster a taste for literary improvement, and to inspire a love of all that is pure in thought, beautiful in expression, and moral in tendency." The Biographical Sketches are detached from the specimens of the authors, which are printed in two separate volumes.

ALEX. THOM & SONS, 87 & 88, ABBEY-STREET, DUBLIN,
Printers to the Commissioners of National Education in Ireland.